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The effects of porcine somatotropin (PST) administration to growing pigs on adipose tissue composition and processed product characteristics

Steven Michael Lonergan
Iowa State University

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by

Steven Michael Lonergan

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GENERAL INTRODUCTION

An increase in consumer demand for lean meat products has increased the interest in efficient production of lean pork. It has been long held that porcine somatotropin, a naturally occurring peptide hormone, promotes pig growth and decreases carcass fat content (Machlin, 1972a). With the use of existing recombinant DNA techniques, porcine somatotropin can be produced in mass quantity. The potential for use of porcine somatotropin (PST) in the pork production industry has been enhanced by this increased supply of PST. Daily administration of PST to growing pigs increases average daily gain (Johnson et al., 1989b) and feed efficiency (Ender et al., 1989b). Carcasses from pigs treated with PST had less average backfat (Evock et al., 1988) and increased lean as evidenced by greater loin eye area (Prusa et al., 1990b) and yield of primary cuts (Ender et al., 1989a). Additionally, intramuscular fat in rib chops was reduced by PST treatment (Prusa et al., 1989a). The beneficial effects of PST treatment have been accompanied by few consistent alterations in fresh pork quality (Prusa etal., 1989b).

To fully understand the effects of PST on growth performance, pork composition, and pork quality, it is important to understand the biochemical and physiological mechanism by which PST alters metabolism. Administration of PST to growing pigs decreased lipogenisis by inducing a insulin resistance in adipose tissue (Walton et al., 1987a). A reduction of lipogenesis decreases the amount of

energy stored in adipose tissue and, therefore, increases the amount of energy available for growth and development of other tissues. Additionally, PST administration increased hepatic production and secretion of insulin like growth factors which promote muscle growth (Boyd and Wray-Cahen, 1989). An understanding of these mechanisms aids an objective review of the effects of PST in pork production and processing.

Although there is much information available concerning the effects of PST on lean pork production, little information is available on the processing characteristics of pork as a result of PST treatment. It has been reported that subcutaneous fat from PST-treated pigs is higher in polyunsaturated fatty acids than fat from controls (Ender et al., 1989a). An additional report indicated that intramuscular lipid from pigs treated with PST was more unsaturated than controls (Prusa et al., 1989a). A more polyunsaturated fatty acid profile may lead to less acceptable processed pork flavor (Rhee et al., 1988b) and texture (Shackelford et al., 1990c).

Given the success of PST administration in promoting efficient production of lean pork, it may become a common practice in the pork production industry. Because a great percentage of the pork carcass is utilized in processed products, it is important to investigate the characteristics of processed pork products from pigs treated with PST.

Explanation of Thesis Format

This thesis is written in an alternate style format consisting of a general introduction, general review of the literature, a publishable paper, and a concluding summary. Citations of references for the general introduction, general review of the literature, and general summary are in accordance with the CBE style manual. The paper consists of a title page, abstract, introduction, materials and methods, results and discussion, conclusions and references. The format for the paper is in accordance with the Journal of Food Science style guide for research papers. The paper has been submitted to the Journal of Food Science.

GENERAL REVIEW OF LITERATURE

Effects of PST on Swine Growth Performance

Until recently, studies developed to determine the effects of exogenous porcine somatotropin (ST) on pork production have utilized purified pituitary porcine ST (Machlin, 1972a, 1972b; Chung et al., 1985). This native product is in limited supply because the only source is porcine pituitary extracts. Machlin (1972a) suggested that this limited supply would probably prohibit the implementation of the growth enhancer in a pork production management system. The costs of extracting the pituitary ST are prohibitive and therefore it was not considered to be a potential cost effective management practice to increase growth performance. With the increased availability of porcine ST through recombinant DNA technology, there has been a renewed interest in utilizing this growth enhancer in swine production. Questions arising about the effectiveness of recombinant porcine ST (PST) to stimulate growth led Evock et al., (1988) to compare equal doses of purified porcine pituitary ST to PST. Results from the comparison led to the conclusion that the two components are equipotent in stimulating growth and feed efficiency. Additionally, pituitary ST and PST increased protein accretion and decreased carcass lipid in a similar manner. These findings indicate that the use of PST in pork production appeared to be a probable means of increasing growth performance. The limited supply of the

purified pituitary ST was no longer a limiting step in the development of this management practice.

Administration of recombinant porcine somatotropin (PST) to growing pigs through injection has been successful in increasing average daily gain (Azain et al., 1989; Johnson et al., 1989b; Smith et al., 1989a). The increase in average daily gain appeared to be PST dose-dependent (Ender et al., 1989b). PST administration reduces feed intake in growing pigs (Azain et al., 1989; Johnson et al., 1989b) and, therefore, feed efficiency improved up to 20 percent (Ender et al., 1989b; Etherton et al., 1986).

In a study to determine the most efficient method of increasing levels of somatotropin in pigs, Johnson et al. (1989b) compared effects of human growth hormone releasing factor (hGRF) to PST. Growth hormone releasing factor is an endocrine messeage than stimulates the secretion of PST. Both methods improved average daily gain and feed efficiency. Direct PST administration showed a greater response in growth performance than did injection of hGRF. The levels of somatostatin, a somatotropin secretion inhibitory protein, were not manipulated in this study and may have diminished the secretion stimulus of hGRF.

Although PST increases daily gain and feed efficiency, other management systems may affect the degree to which growth performance is improved by PST. Campbell et al. (1988) and Nossamon et al. (1989) studied the effects of restricting feed energy intake of control pigs and pigs treated with PST. In both studies,

restricting energy had a negative effect on lean growth in control and PST treated pigs. In all cases, PST treated pigs had greater amounts of moisture and protein accretion than control pigs. Control pigs had greater amounts of lipid accretion within each feed energy group. Fat accretion was highest in ad-libitum fed pigs regardless of PST treatment.

Caperna et al. (1989) compared 11, 15, 19, 23, and 27 percent crude protein rations for pigs injected with 0 or 100 μg PST/day. Protein accretion was not improved by feeding greater than 15 percent protein rations in either treatment group. The authors suggested that PST may improve the metabolic efficiency by which amino acids are utilized. In contrast, Smith et al. (1989b) concluded that dietary crude protein must be at least fourteen percent for PST to improve growth and feed efficiency in growing pigs. Campbell et al. (1989) suggested the production of an optimum growth resoponse in PST treated pigs required increased protein (including increased lysine) in swine rations. Although the influence of dietary protein in growing pigs treated with PST is uncertain, it does seem clear that an increase in dietary lysine is required to optimize protein accretion in PST treated pigs (Krick et al., 1990). These authors also hypothesized that PST may increase the efficiency of absorbed amino acids used in protein accretion.

To determine if a maximally effective dose of PST could be defined, Etherton et al. (1987) administered 0, 10, 30, and 70 μg PST/kg body weight daily to 50 kg barrows. Growth rate and feed

efficiency were improved with increasing dosage. Serum IGF-1 concentration was increased in a similar manner. Additionally, no antibodies to PST were detected in any of the pigs. These findings indicated that the effect of PST on growth performance is dose dependent. None of the parameters measured had plateaued, which indicated that the optimally effective dose of PST may be greater than 70 μg/kg body weight per day. Evock et al. (1988) suggested that daily administration of PST at a rate of 140 μg/kg body weight impairs pig mobility. This impairment of mobility was attributed to the development of osteochondrosis in the pigs administered the 140μg/kg body weight daily dosage of PST. Although the rate of lean muscle growth and carcass lipid reduction were the greatest using this dose, the impairment of mobility would be a limiting factor in pork production.

Effects of PST on Pig Carcass Composition

Machlin (1972b) demonstrated that treatment of growing pigs with highly purified pituitary ST significantly decreased backfat thickness and increased loin eye area at the tenth-rib. Furthermore, treatment with ST increased the percentage yield of the four lean wholesale cuts. Dressing percentage was decreased in carcasses from ST treated pigs. In another study utilizing purified pituitary ST, Chung et al. (1985) found somewhat contrasting results. Treatment with ST did not significantly decrease backfat thickness and showed

no improved percentage yield in ham, shoulder, or belly. ST treatment resulted in a lower dressing percentage, although the difference was not significant. The slight decrease in dressing percentage was attributed to increased liver, kidney and heart weight in response to ST treatment. Total muscle mass was greater in carcasses treated with ST when compared to control pigs. Carcasses in the PST treatment group had increased loin weights and, interestingly, higher concentrations intramuscular fat in the loin than controls.

Prusa et al. (1990b) found carcasses from pigs treated with PST had a significantly greater loin muscle area and decreased carcass fat percentage. Evock et al. (1988) demonstrated that exogenous PST administration in growing pigs decreased average backfat depth, while it increased skinned ham weights and loin eye area. To determine carcass composition, proximate analysis of carcass soft tissue (muscle and adipose tissue) revealed that carcasses from pigs treated with PST had a greater percentage of water and protein with a lower percentage of lipid than those from control pigs. Accordingly, total adipose tissue mass was decreased and muscle mass was increased in carcasses from PST treated pigs.

It has become clear that treatment of growing pigs with daily doses of PST decreases total carcass fat (Ender et al., 1989a) and, specifically, average backfat (Johnson et al., 1989b). PST treatment of pigs also increased total muscle mass as indicated by increased loin eye area (Smith et al., 1989a), ham muscle mass (Johnson et al.,

1989b), total separable lean (Theil et al., 1990), and yield of primary cuts (Ender et al., 1989a). Evock et al. (1988) also observed a PST dose dependent increase in carcass moisture and ash percentages. All of these results indicate production of leaner, higher yielding pork carcasses is possible through the administration of PST.

Beermann et al. (1990) found that the highest daily dose of PST used (200 μg/kg body weight) was most effective in reducing intramuscular lipid. However, no increase in muscle mass was observed with daily doses greater than 120 μg/kg body weight. The authors suggested that this illustrates a two-fold action of PST. The first action is a direct effect reducing adipose tissue mass while the second, growth promoting effect, is mediated through insulin-like growth factors. Similar effects are demonstrated by Evock et al. (1988) where reduction of adipose tissue mass continued with daily doses of PST up to 140 μg/kg body weight, but total muscle mass was not significantly improved by daily doses greater than 70 μg/kg body weight.

Effects of PST on Fresh Pork Composition

It is clear that PST supplementation during growth significantly decreases intramuscular fat content in fresh loins (Boles et al., 1990; Williams et al., 1990; Prusa et al., 1989a), hams (Beermann et al., 1990), and shoulder muscles (Prusa et al 1989b). The reduction of fat in loins (Lentsch et al., 1990) and hams (Beermann et al., 1990)

appears to be PST dose dependent. In contrast, Prusa et al. (1989a) reported no significant decrease in intramuscular fat with an increased daily dose of PST from 4 to 8 mg/day.

Prusa et al. (1989a) did not observe an increase in moisture content in rib chops due to PST administration. While PST treatment of growing pigs increased moisture percentage in semimembranosus, semitendinosus, and biceps femoris muscles, the increase was not significant (Prusa et al., 1989b). This study did, however, reveal a significant increase in moisture percentage in triceps brachi muscles from PST treated pigs when compared to controls. Beermann et al. (1990) reported an increase in moisture content in the semitendinosus due to PST treatment but the semitendinosus moisture:protein ratio was not altered by PST administration.

Protein concentration in the longissimus dorsi was increased by PST administration (Beermann et al., 1988). Prusa et al. (1989a) also observed increased protein concentration in raw boneless pork chops due to PST treatment, however the increase was not significant. Protein concentration in the triceps brachi, psoas major, semimembranosus, and biceps femoris muscles were not significantly increased by PST supplementation (Prusa et al., 1989b). In this study, muscles responded differently to PST administration. Protein content was significantly increased in the semimembranosus by PST administration. Beermann et al. (1990), however, reported no trend indicating a PST related increase in protein concentration in the semitendinosus.

PST administration to growing pigs does not appear to alter the composition of meat proteins. Lentsch et al. (1990) observed no differences due to PST administration in the number or calculated molecular weight of myofibrillar proteins as analyzed by SDS-PAGE. Caperna et al. (1990) reported that collagen increased proportionally with total protein in muscles from pigs treated with PST. Furthermore, these authors suggested that PST treatment did not affect collagen fiber cross-linking or maturation.

Adipose tissue composition is altered by PST administration. Kramer et al. (1990) observed decreased lipid concentrations and increased moisture and protein concentrations in adipose tissues from pigs treated with PST when compared to control pigs. Ender et al. (1989a) reported a "softer" adipose tissue from pigs treated with PST. This observation was attributed to an increase in unsaturated fatty acids (primarily linoleic acid) rather than an increase in moisture composition. Mourot (1990) also reported an increase in polyunsaturated fatty acids in subcutaneous fat from PST produced pigs. In contrast, Prusa (1990) found no difference in fatty acid profiles in subcutaneous fat from PST-treated and control pigs. Intramuscular fat from broiled boneless rib chops originating from PST treated pigs had a slightly less saturated fatty acid composition when compared to the control group (Prusa et al., 1989a). Further investigation of PST effects on adipose tissue composition is imperative to determine if increased moisture (Kramer et al., 1990) or an altered fatty acid profile (Ender et al., 1989a; Prusa et al.,

1989a) would affect pork shelf life and processed pork characteristics.

The effects of PST administration on nutritional components in pork have also been measured. Lentsch et al. (1990) observed that cholesterol content in cooked muscle did not differ due to PST treatment. Prusa et al. (1989a) reported that cholesterol content of cooked rib chops from pigs treated with 8 mg PST daily was greater than cholesterol content of cooked chops from controls or pigs treated with 4 mg PST per day. Although the increase in cholesterol content was statistically significant, it may not be of significance from a nutritional standpoint.

Iron content in cooked longissimus dorsi muscle (Lentsch et al., 1990) and cooked rib chops (Prusa et al., 1989a) were not significantly altered by PST administration during growth.

Thiamin content is of interest because it is notably greater in pork than other meat products. A three ounce portion of pork contains seven times as much thiamin as the same portion of beef (AMI, 1987). This nutritional advantage makes thiamin an interesting component in pork. Additionally, thiamin is involved in carbohydrate metabolism (Stryer, 1988b). If carbohydrate metabolism is altered by PST administration, the thiamin concentration may be changed as well. Prusa et al. (1989a) observed a lower concentration of thiamin in cooked muscle from PST treated pigs than controls. The authors suggested that carbohydrate metabolism may be more efficient and thiamin requirement may be decreased in PST treated animals.

Mechanisms of the Action of PST During Growth

To better understand the compositional and possible quality changes in pork due to PST, it is important to understand the effect of PST on target cells and physiological condition of treated animals. Observations of the physiological conditions of PST treated pigs offer some insight of the mechanisms by which lean growth is improved by PST. Exogenous PST administration increased live pig serum concentrations of insulin, IGF-1, glucose, and non-esterified fatty acids (Johnson et al., 1989a).

Regulation of Somatotropin Secretion

Somatotropin (ST) is a large complex peptide containing two disulfide bonds. ST is synthesized by specific cells types in the anterior pituitary gland. Five to fifteen milligrams of ST is stored in the pituitary gland. Secretion of ST from the hypothalamus is controlled by a complex regulatory system. The central nervous system controls the secretion of somatotropin releasing factor (Della-Ferra et al., 1986) and somatostatin, a somatotropin secretion inhibitory protein (Ferland et al., 1976). Regulation of these controlling factors is dependent on physiological conditions and mediated through the central nervous system.

Abrams et al. (1971) reported that low levels of blood plasma glucose stimulated the secretion of somatotropin releasing factor

followed by a substantial increase in ST secretion. Additionally, a high level of cellular 2-deoxy glucose (a form of glucose not utilized by tissues) will stimulate ST secretion (Dauhaday, 1972a). These observations reveal the role of ST releasing hormone to increase secretion when energy is not readily available. Levels of amino acids available through dietary sources also appear to affect secretion of ST releasing factor. Arginine appears to be one of the more effective amino acids in the stimulation of ST releasing factor. The suggestion has been made that secretion of ST induced by amino acids is a mechanism for stimulating protein synthesis when precursors are available (Clemmens, 1970). The rise in ST in response to amino acid availability is short term and not large enough to justify ration alteration as a means to increase growth performance (Etherton and Kensinger, 1984).

Dubreuil et al. (1987) found that the overall secretion of ST in pigs decreased with age with the greatest decrease observed after seven weeks. ST secretion in response to a synthetically produced ST releasing factor decreased with age. These observations could possibility be explained by a change in sensitivity of the somatotrophs to ST releasing factor or a change in ST content in the pituitary gland during the growth period.

Differences in ST secretion due to sex have been observed. Dubreuil et al. (1987) reported that gilts responded to ST releasing factor injection with a greater amount of ST secreted than barrows.

This may suggest that a lower level of androgens or a presence of estrogens may affect ST secretion.

While secretion of ST appears to be the controlling factor in regulation of ST plasma levels, ST synthesis is also controlled. Yaffe et al. (1984) demonstrated an intricate dependence on another endocrine system. The rate of transcription of the growth hormone gene is positively controlled in proportion to the concentration of thyroid receptor complexes. Glucocorticoids also appear to work in a synergistic fashion with these complexes to increase growth hormone mRNA synthesis and consequently ST peptide expression.

Action of Somatotropin on Adipose Tissue

Somatotropin has been shown to play a central role in growth (Etherton, 1988). While ST stimulates an anabolic response in most tissues, its action on adipose tissue is a reduction of lipid accretion. ST may act through several different pathways to decrease the amount of fat deposited in adipose tissue. These possibilities include a decrease in triglyceride synthesis, or an increase in lipolysis and fatty acid oxidation (Goodman, 1988). The fat cell readily stores preformed fat that enters by way of the gut or is synthesized in the liver. Additionally, the fat cell can synthesize fatty acids from glucose or amino acids. Fat is stored in adipose tissue in the form of a triglyceride which is a triester composed of three molecules of long chain fatty acids per molecule of glycerol. Triglycerides are

synthesized continually from free fatty acids and alpha glycerol phosphate, which is a derivitive of glucose. Triglycerides are broken down by a hormone sensitive lipase. This lipase is dependent on cyclic adenosine phosphate (cyclic AMP) (Steinberg and Huttunen, 1972) which is stimulated primarily by epinephrine. The activity of the lipase involves the splitting off of the first fatty acid from the triglyceride and is thought to be the rate determining factor in lipolysis (Goodman, 1988). The process of lipolysis and esterification appears to be an on-going cycle. Thus ST could change the rate of fatty acid mobilization through acceleration of lipolysis or by decreasing the rate of esterification. Either of these actions would be consistent with reports that ST treatment decreased carcass fat in rats (Duquette et al., 1984) and pigs (Machlin, 1972b).

The products of lipolysis are free fatty acids and glycerol (Stryer, 1989a). Free fatty acids will either be utilized by the adipocyte in lipogenesis or released from the cell. Glycerol, however, cannot be utilized in lipogenesis in the adipocyte because glycerol kinase is not present within the cell. Glycerol kinase stimulates the reaction that produces alpha-glycerol phosphate, the essential precursor to triglyceride synthesis. Therefore, glycerol release from the adipocyte is an accurate measure of lipolysis (Stryer, 1989a),

Most evidence has indicated that ST decreases lipid accretion through a reduction in lipogenesis. In some studies involving rats, ST has been shown to play a part in the stimulation of lipolysis. In a study to identify the effects of hormones on lipolysis, Goodman

(1969) demonstrated that bovine ST combined with dexamethasone, a synthetic glucocorticoid, increased glycerol release in isolated rat adipocytes. This suggested that ST may have a role in stimulation of lipolysis if allowed to interact with the affects of glucocorticoids. ST alone has also increased lipolysis of rat adipocytes as demonstrated by Katocs et al. (1973), and Wieser et al. (1974). Duquette et al. (1984), however, attributed an observed lipolytic effect to anterior pituitary hormone contaminants of ST preparation. The lipolytic effect of ST may be exclusive in rat adipose tissue. Katocs et al. (1973) and Duquette et al. (1984) concluded that ovine ST had no direct lipolytic effect on ovine adipose tissue. Etherton et al. (1989) reported that porcine ST did not stimulate lipolysis in porcine adipocytes or adipose tissue. Kramer et al. (1990), however, did observe an increase in glycerol release in adipose tissue from pigs treated with porcine ST. The question of ST's role in lipolysis of adipose tissue is still uncertain.

Bornstein et al. (1983) demonstrated a reduction of fatty acid synthesis by human growth hormone (hGH) and a hGH carboxy terminal peptide (hGH 172-191) in rat adipocytes. Treatment with hGH or hGH 172-191 resulted in an inhibition of acetyl CoA carboxylase. The mechanism proposed by these workers is a small molecular "second messenger" response to hGH and hGH 172-191 which inhibits the acetyl CoA carboxylase phosphatase activity. This phosphatase is necessary to convert the inactive phosphorylated form of the carboxylase to the active (dephosphorylated) form. Acetyl CoA

carboxylase activity catalyzes the critical step to malonyl CoA in fatty acid synthesis. Reduction in the activity of acetyl CoA carboxylase then results in decreased fatty acid synthesis. The observation that the carboxyl terminal sequence stimulates a response similar to the one of hGH indicated an active binding site on the cell exists for this portion of the peptide. In an earlier study, Goodman (1962) observed that ovine ST caused an impairment in the capacity of the adipose tissue from hypophysectomized rats to synthesize lipid from non-lipid precursors. This also suggested that ST may interact with enzymes in pathways that lead to amino acid or glucose carbon incorporation in fatty acids. Schoenle et al. (1979) showed that the transport of glucose in the fat cell is controlled by ST. ST apparently induces a change in the cellular glucose carrier system that leads to a restriction in glucose transport. All of these observations lead to the decreased lipid accretion that is observed in live animals (Machlin, 1972b).

In a study designed to examine the action of insulin and porcine ST, Walton et al. (1986) found that the effects of porcine insulin on porcine adipose tissue included increased glucose metabolism and lipogenesis. It was also determined that porcine ST directly antagonized the action of physiological concentrations of insulin. Porcine ST apparently induced an insulin resistance *in vitro*. If porcine ST induces an insulin resistance *in vivo*, the effects would include an increased blood glucose concentration due to reduced cellular uptake and increased blood insulin levels in response to the

higher blood glucose levels. The end result would include a repartitioning of the glucose energy to other tissues (most importantly muscle) and increased hypertrophy in other cells due to the higher levels of insulin. Walton et al. (1986) proposed that these results explain the diabetogenic effects of ST that are suggested by Goodman (1962) which included an increase plasma levels of insulin. Wray-Cahen et al. (1990) found that ST administration induced an insulin resistance in growing pigs. ST treatment of growing pigs was found to decrease whole body sensitivity to insulin without altering the maximal response to insulin. Therefore, it appears that the *in vitro* observations by Walton et al. (1986) do explain the activity of ST *in vivo*.

Walton et al. (1986) hypothesized that ST induced insulin resistance was a result of ST altering the recognition of insulin at the level of the receptor. Etherton et al. (1989), however, reported no receptor alteration and suggested that the observed insulin resistance was a result of an alteration of 1) lipogenic enzymes (Bornstein, 1983), 2) second messengers (Bornstein et al., 1983; Goodman, 1968), or 3) glucose transporters (Schoenle et al., 1979).

It has been observed that the ST induced insulin resistance is a dose dependent response. This indicates that the action of porcine ST on adipose tissue is direct and not mediated by any locally produced compounds (Etherton et al., 1989).

Effects of Somatotropin on Liver

The action of somatotropin on liver is clearly the stimulation of synthesis of insulin-like growth factors (DeVol and Bechtel,1989). Insulin-like growth factor-1 (IGF-1) mediates many of the anabolic effects of ST (Schoenle et al., 1985). Insulin-like growth factor-2 (IGF-2) is the fetal counterpart of IGF-1 (Daughaday et al., 1986; Adams et al., 1983). It has been shown, however that IGF-2 is synthesized by certain adult tissues (Shimatsu and Rotwein, 1987). This observation suggests that IGF-2 may have a role in post-natal growth.

The binding of ST to liver microsomes is directly related to IGF-1 production (Boyd and Wray-Cahen, 1989). Chronic administration of porcine ST to liver membranes increased liver microsome binding of ST and, subsequently, synthesis and secretion of IGF-1 (Chung et al., 1986). This illustrated that the action of ST on the liver are additive. The results of this study indicated that IGF-1 production will increase with chronic treatment of ST because the concentration of ST binding sites on the liver was not a limiting factor.

Insulin like growth factors were first recognized by Salmon and Daughaday (1957). These authors originally used the term "sulfation factor" to describe the potent mitogens' action on developing cartilage. In 1972, Daughaday et al. (1972b) proposed the name "somatomedin" refering to the hormonal relationship to somatotropin

and the target tissues of the agent. The current nomenclature of these compounds refers to the similar homology and action of insulin.

Insulin-like growth factors share considerable homology with insulin (Schalch et al., 1982). Additionally, IGFs and insulin both induce a mitogenic response in cells. IGF-1 has been shown to be present at higher levels than IGF-2 during post natal growth and have a larger impact on growth (DeVol and Bechtel, 1989). Insulin-like growth factors are considered to be the ultimate endocrine link in the cascade of hormones regulating cell growth (Spencer, 1985). IGF receptors have been found in cartilage, liver, and, most notably, in muscle (Daughaday 1982). The action of plasma IGF on these tissues have been shown to be hypertrophic and hyperplasic (Spencer, 1985). Given the evidence that the actions of ST are mediated by IGF-1 (Florini, 1985) it has been suggested that increasing plasma IGF-1 levels would result in similar growth responses. Studies involving farm animals to test this hypothesis have been limited due to the relatively scarce quantities of recombinant IGF-1 available. Studies utilizing cell cultures have reported that free IGF-1 does not increase growth as well as ST (Boyd and Bauman, 1989). Clemmons et al. (1987) estimated that ST, on a molar basis, is 10- to 15-times more potent than free IGF-1. It has been shown that free IGF-1 increases lipid metabolism - much like insulin does in bovine adipose tissue (Etherton et al., 1986a) and porcine adipose tissue (Walton et al., 1987a). These findings were surprising because increased lipid metabolism was not observed

when IGF-1 levels were stimulated by ST (Walton et al., 1987b). These results suggested that there may be another agent that acts with IGF-1 to increase lean muscle growth.

Zapf et al. (1986) demonstrated that ST modulates the effects of IGF-1 through two IGF binding proteins. These IGF binding proteins bind free IGF-1 and direct it towards target tissues. The larger (150 kDa) binding protein is ST concentration dependent while the smaller (40 kDa) binding protein is independent of ST concentration (DeVol et al., 1989). When ST is administered, the concentration of the larger binding protein increases as does IGF-1 (Zapf et al., 1986; Schalch et al., 1982). Accordingly, the plasma concentration of the large binding protein is severely diminished in hypophysectomized swine (Buonomo et al., 1989).

The half life of IGF-1 is greatly increased when bound to the binding proteins (Walton et al., 1987a). Therefore, the action of ST not only includes increasing IGF-1 levels but also the maintenance of these enhanced levels through the binding proteins. This allows for growth generating action of extra-hepatic tissues including muscle. The increase in IGF-1 activity seen with the binding protein may also be a result of the binding protein directing the IGF-1 to the target cell (Zapf et al., 1986).

The 150 kDa binding protein is involved in blocking the lipogenic effect of IGF-1 on porcine adipose tissue (Walton et al., 1987b). The secretion of this binding protein is triggered in response to an increase in ST plasma concentration. Therefore, while ST

administration increases IGF-1 secretion, it blocks the lipogenic effect of IGF. This explains while ST administration increases IGF-1 levels, increased lipogenesis is not observed.

The effects of ST on the liver are the stimulation of the synthesis of insulin-like growth factors (DeVol et al., 1989) and IGF binding proteins (Zapf et al., 1986). The increase in these peptides results in increased hypertrophy and hyperplasia (Spencer, 1985) while limiting those effects on adipose tissue. This results in a further repartitioning of energy for lean muscle growth which is stimulated by IGF-1.

Effects of Somatotropin on Muscle

In addition to increasing hepatic IGF-1 synthesis, ST treatment increased muscle synthesis of IGF-1 (Turner et al., 1988). The finding that muscle cells (Jennische et al., 1987) and muscle tissue (Turner et al., 1988) synthesize IGF-1 mRNA indicates that growth in muscle may be regulated in a localized as well as an endocrine manner.

The production of IGF-1 in muscle cells is under regulation of ST (Murphy et al., 1987). The mechanism by which ST stimulates muscle cell synthesis of IGF-1 is uncertain, but it does appear to have different effects on different muscles. Evock et al. (1990) found that ST treatment increases mRNA/DNA ratios in the longissimus dorsi. This suggested an increase in transcription or a decrease in the turnover of the mRNA. The effect of ST treatment on the

semimembranosis muscle, however, was an increase in DNA content with no increase in the mRNA/DNA ratios. Grant et al. (1990) found that IGF-1 gene expression in the liver and longissimus dorsi were under control of ST. In contrast to earlier reports, these authors concluded that while ST treatments increased IGF-1 mRNA synthesis in the liver, it did not do so in the longissimus dorsi. These observations may explain why differences in individual muscle composition in response to PST treatment were observed by Prusa et al. (1989b).

DeVol et al. (1989) concluded that two separate mechanisms control IGF synthesis in muscle. One system may be ST dependent while the other is ST independent. This may, in part, explain the contrasting reports demonstrating the mechanism by which IGF-1 synthesis is controlled in muscle cells. Although it appears that locally synthesized IGF-1 may be a more specific mitogen in muscle cells, its action is similar to hepatically synthesized IGF-1 (Boyd and Wray-Cahen, 1989).

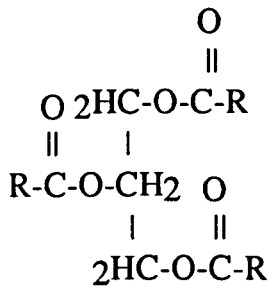
Action of Somatotropin on Other Tissues

Growth of tissues other than muscle are stimulated by ST. The increased levels of IGF-1 produced by the liver in response to ST increases growth in skin cell, developing bone and cartilage, and many organs (Spencer, 1985). This increase in growth is also a response to the repartitioning effect of ST on adipose tissue. A growth promoting action on internal organs explains the decreased hot

carcass yield from pigs treated with PST observed by Chung et al. (1985).

Lipid Composition of Pork Adipose Tissue

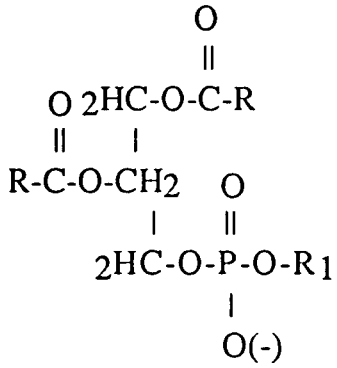
It is clear that somatotropin directly decreases lipid metabolism (Etherton, 1988). Therefore it is important to review the factors that affect porcine adipose tissue composition to better understand the effects of PST on lipid composition in pigs. Adipose tissue represents the major reserve of energy for members of the animal kingdom (Body, 1988). Natural fats are composed principally of glycerol esters of straight chain carboxilic acids generally having an even number of carbon atoms. Glycerol can combine with one, two, or three fatty acids to form mono-, di-, and tri-glycerides. Additionally, glycerol can combine with two fatty acids and one alcohol to form phospholipids. Triglycerides are predominant in pork fat. They are chemically very homogeneous and have the general formula of:



The R groups represent different saturated and unsaturated fatty acids attached to the glycerol molecule (Dugan, 1978). The

principal fatty acids in pork adipose tissue (Table 1) are oleic (18:1), palmitic (16:0), stearic (18:0) and linoleic (18:2) (Body, 1988). Pigs typically accumulate linoleic acid in adipose tissue from dietary sources (Body, 1972).

Phospholipids are present at much lower levels than triglycerides in adipose tissue. Phospholipids generally function in plasma membranes and have the general formula of:



The R groups again indicate a saturated or unsaturated fatty acid. The R1 group represents the alcohol bound to the phosphoryl group at the third position of glycerol. Compared with the related triglycerides, phospholipids contain a higher proportion of polyunsaturated fatty acids. The increased level of unsaturation in phospholipids is required for membrane functions as part of the lipid-protein complex of individual cells, in the essential fatty acid transport system and as regulators for overall animal growth (Stryer, 1989b).

Table 1. Principal Fatty Acid Composition of Triglycerides in Porcine Adipose Tissue[a]

Fatty acid	Notation	% of Total [b]
Myristic	14:0	1.3
Pentadecanoic	15:0	traces
Palmitic	16:0	24.2
Heptadecanoic	17:0	0.5
Stearic	18:0	14.7
Pentadecenoic	15:1	traces
Palmitoleic	16:1	3.1
Heptadecenoic	17:1	0.5
Oleic	18:1	45.6
Linoleic	18:2	7.7
Linolenic	18:3	2.2

[a] Adapted from Body (1988)

[b] Fatty acid composition is reported as a percent of the total lipid content.

Factors Affecting Pork Fatty Acid Composition

Sex

It has been long held that backfat from barrows is composed of a greater percentage of saturated fatty acids than backfat from gilts (Johns, 1941). Koch et al. (1968a) reported that backfat from spayed gilts had lower concentrations of linoleic acid than backfat from

boars, barrows, or intact gilts. In this study, backfat from boars had significantly higher concentrations of linoleic acid than barrows and gilts. Villegas et al. (1973) compared fatty acid composition in subcutaneous fat from barrows and gilts and found that backfat from gilts contained more linoleic acid than barrows. Additionally, the ratio of saturated to unsaturated fatty acids was slightly higher in gilts when compared to barrows (Villegas et al., 1973). Koch et al. (1968b) reported that backfat and leaf fat from barrows had significantly higher concentrations of palmitic, and stearic acids and lower concentrations of linoleic acid than adipose tissue from these locations in gilts. In the same study, sex had no effect on fatty acid composition in intramuscular fat. Brooks (1964) reported similar findings in depot fat but found increased levels of unsaturated fatty acid in intramuscular fat in gilts. Geri et al. (1990) reported that while subcutaneous fat from gilts contained significantly greater amounts of polyunsaturated fatty acids, backfat from barrows had greater amounts of monounsaturated oleic acid. In contrast, Martin et al. (1972) reported that belly fat from gilts contained significantly less linoleic acid than belly fat from barrows.

Anatomical Location

Considerable anatomical variation in fatty acid composition and distribution has been reported as early as 1944 (Hilditch, 1944). Villegas et al. (1973) observed that the outermost layer of backfat

contained more total unsaturated fatty acids than the middle and inner layers. Accordingly, the middle layer of backfat possessed a more unsaturated fatty acid profile than the inner layer. Perirenal (leaf) fat had a higher percentage of saturated fatty acids and a significantly lower ratio of saturated to unsaturated fatty acids than any subcutaneous location. These results are in agreement with Koch et al. (1968a). These authors indicated that the inner layer of backfat contains more stearic and less palmitoleic acids than the outer layer. Koch et al. (1968b) reported similar findings and suggested that the inner layer of backfat exhibited a more extensive turnover of fatty acids and is metabolically more active than the outer layer.

In an extensive comparison between seven separate anatomical locations, Sink et al. (1964) identified several differences in fatty acid profile due to carcass location. Leaf fat contained significantly more palmitic acid than the outside layer of fat over the shoulder and the outside and inside layer of fat over the last rib and last lumbar vertebrae. Leaf fat contained less oleic acid than all subcutaneous depots. Unsaturated fatty acid concentration followed a trend reverse of the saturates. The unsaturated fatty acids were higher in concentration in subcutaneous fat when compared to leaf fat and the outer layer of subcutaneous fat when compared to the inner layer.

Differences between fatty acid content in different anatomical locations may in part be explained by lipogenic enzyme activity. Anderson et al. (1973) observed differences in lipogenic enzyme activity between layers of subcutaneous fat. After 3.5 months of age,

the lipogenic activity in the middle and inner layers of subcutaneous fat was higher than activity in the outermost layer. These observations, along with the observation that the outer layer developed the earliest during growth, may indicate that the differences in fatty acid profile may be related to time of deposition during growth and metabolic activity. Similar differences were noted in the lipogenic activity of perirenal adipose tissue. The lipogenic enzyme activities of perirenal adipose tissue were higher than all subcutaneous areas at 3.5 months. Following this age, the perirenal lipogenic enzyme activity level was higher than levels in the only outer subcutaneous layers. Koch et al. (1968b) also suggested that the inner layer of subcutaneous fat was the most metabolically active dution the finisthing stage.

Differences in fatty acid composition at different locations within similar fat layers may not exist. St. John et al. (1987) observed only a difference in stearic acid when comparing inner layers of subcutaneous fat over the longissimus dorsi and semimembranosus, with the fat over the longissimus having the greater portion.

Fatty acid composition of intramuscular lipid varies from subcutaneous adipose tissue. Intramuscular lipid in the longissimus dorsi (Greer et al., 1965) and semitendinosus (Brooks, 1972) contained significantly greater concentrations of oleic acid than subcutaneous or perirenal fat. Marchello et al. (1983) observed similar differences between intramuscular and subcutaneous fat. Intramuscular fat from the longissimus dorsi was significantly lower

in linoleic acid and higher in oleic and palmitic acid than subcutaneous fat. Additionally, intramuscular fat had a lower percentage of stearic acid than leaf fat and depot fat from the inner layer of subcutaneous fat over the last rib region. Koch et al. (1968b), however, did not observe any fatty acid composition differences between the outer layer of subcutaneous fat and intramuscular lipid.

Muscle anatomical location apparently affects the fatty acid profile of intramuscular fat. Rhee et al. (1988b) found total lipids from semitendinosus muscles were more unsaturated than total lipids from the semimembranosus. The level of saturation in the longissimus dorsi and psoas major was intermediate to the semimembranosus and semitendinosus. The psoas major contained greater concentrations of polyunsaturated fatty acids than any other muscle in the comparison. It was also determined that the longissimus dorsi and semitendinosus contained higher concentrations of monounsaturated fatty acids than the psoas major and semimembranosus. Allen et al. (1967) identified differences in intramuscular lipid fatty acid composition between longissimus dorsi, psoas major and diaphram muscles. Fatty acid composition of the lipid extract from these muscles indicated that the longissimus dorsi had significantly greater concentrations of myristic and oleic acids and lower concentration of linoleic acid than either the diaphram or psoas major.

Body and Carcass Composition

There are some indications that pig body and subsequent carcass composition (in regards to muscle mass and fat cover) is related to fatty acid composition and distribution. Martin et al. (1972) suggested that degree of finish is related to percentage of saturated fatty acids in belly fat. Correlations among measurements of lean (loin eye area and percentage yield of lean cuts) and fat (total backfat) and fatty acid components indicated that measures of fat were positively, and lean negatively correlated to percentages of myristic, palmitic, and stearic acids. Accordingly, measures of fat were negatively, and lean positively correlated with linoleic acid. This is in agreement with Piedrafita (1990) where average backfat and last rib backfat depths were negatively correlated with linoleic and linolenic acids. Additionally, fat cover was directly related to stearic acid in the middle layer of subcutaneous backfat. Loin muscle area was directly related to oleic, linoleic, and linolenic acids. Brooks et al. (1971) found that linoleic acid was positively correlated with muscle mass and negatively correlated with total carcass fat.

Breed and Sire

Lush et al. (1936) reported significant sire effects on porcine fat firmness. Villegas et al. (1973) found that breed affects fatty acid

composition and suggested that genetic background may affect fatty acid profiles in porcine subcutaneous fat. Koch et al. (1968a) reported that sire significantly affected linoleic, palmitic, palmitoleic, and stearic acid composition, Geri et al. (1990) found high heritability estimates for all major fatty acids in the outer layer of subcutaneous fat. Kellog et al. (1977), on the basis of similar results, suggested that fatty acid content could be genetically manipulated.

Variation in fatty acid content was also observed between breeds (Villegas et al., 1973). Subcutaneous fat from Hampshire pigs contained less saturated and more unsaturated fatty acids than that of Duroc pigs. Total unsaturated fatty acids in the backfat of Yorkshire and Crossbred pigs were intermediate between that of Duroc and Hampshire pigs. Honkavaara (1989) also reported a strong relationship between breed and fatty acid composition of intramuscular and subcutaneous fat.

Diet

The effect of diet on fatty acid composition of porcine lipids is well documented (Brooks, 1971; Garton et al., 1951; Koch et al., 1968b; Wahlstrom et al., 1971). Swine are monogastric and the introduction of various fats in growing rations can markedly alter the lipid composition of porcine tissues. Dietary fats more unsaturated than pork lipids cause an increase in unsaturation and dietary fats

less unsaturated yield a decrease in unsaturation of pork lipids (Dahl et al., 1965).

Inclusion of whole roasted soybeans (a concentrated source of linoleic acid) at levels of twenty percent in swine rations increased levels of linoleic and linolenic acids in subcutaneous fat (Villegas et al., 1973). Diets containing fifty percent cooked soybeans increased the level of linoleic acid at the expense of oleic acid in backfat (Brooks, 1971; Wahlstrom et al., 1971). Koch et al. (1968b) recognized this same effect and suggested that preferential deposition of linoleic acid lowered the level of total saturated fatty acids. These authors suggested that the pig's metabolism attempted to maintain a fairly constant level of saturated fat by altering the deposition of oleic acid. Marchello et al. (1983) reported that the introduction of sunflower seeds high in linoleic acid increased linoleic acid at the expense of oleic and stearic acid in depot fat as well as intramuscular fat. Koch et al. (1968b) found that while diets high in linoleic acid significantly increased the level of unsaturation in leaf and subcutaneous fat, the effect on intramuscular fat was less pronounced. This is in agreement with Greer et al. (1965) where fatty acid composition of intramuscular fat appeared to be less responsive to altered dietary fatty acids.

An increase in dietary oleic acid through inclusion of 10 and 20 percent canola oil significantly increased concentrations of oleic, linoleic and linolenic acids and decreased myristic, palmitic and stearic acid content (St. John et al., 1987). High levels of dietary oleic

acid were introduced to growing gilts through a sunflower oil high in oleic acid (Rhee et al., 1988a). While diet had no affect on growth performance or carcass yield, it was recognized that carcass fat from gilts in the experimental group was softer than that of control gilts. Fatty acid separation determined that gilts fed the the high oleic acid ration had significantly higher concentrations of monounsaturated fatty acids (principally oleic) in subcutaneous fat and, to a lesser extent, intramuscular lipid. Polyunsaturated fatty acids were not altered by the high oleate ration. Garton et al. (1951) found lipids characteristic of whale oil (arachidonic and erucic acids) were found in the outer backfat layer of pigs fed a diet rich in whale oil. All of the heretofore mentioned results certainly suggest that the dietary fat was passed into the fat depot. Inclusion of ten percent tallow to a control ration did not alter levels of saturated fatty acids in depot fat of experimental pigs compared to controls (Koch et al., 1968b). The tallow diet contained higher levels of saturated fatty acids, primarily palmitic, than the control ration. Brooks et al. (1971) found that replacing twenty percent of the control ration with tallow increased stearic and linoleic acids while decreasing palmitoleic and oleic acids in depot and intramuscular fat. It was suggested that even the lower levels of linoleic acids in tallow were preferentially deposited. Body (1972) also reported that dietary linoleic acid is preferentially deposited in porcine depot fat.

Effects of PST and Diet on Fresh Pork Quality

Daily supplementation of PST to growing pigs had no effect on fresh pork color (Ender et al., 1989a). In contrast, Beermann et al. (1990) observed a darker color in the semitendinosus muscle from pigs treated with PST compared to controls. The darker color was observed using both subjective and quantitative measurements of color. Solomon et al. (1989) reported a lighter color in muscles from pigs treated with PST. In this study, the ultimate pH was also significantly lowered by treatment with PST. Beermann et al. (1990) measured a .1-.2 pH increase in the semitendinosus from PST treated pigs compared to controls. Ender et al. (1989a) reported no significant differences in pH due to PST. This is in agreement with Prusa et al. (1989b) where ultimate pH in triceps brachi, psoas major, semitendinosus and biceps femoris muscles were not significantly altered by PST administration. Water holding capacity (WHC) did not differ in muscles from PST treated and control pigs (Ender et al., 1989b; Prusa et al., 1989b). Solomon et al. (1989) observed a decrease in WHC in the longissimus dorsi muscles from pigs treated with PST. Differences in these studies may reflect variation in genetics or handling of pigs used as experimental units.

Meat tenderness, as measured by Warner-Bratzler shear values, has not been affected by PST (Beermann et. al., 1988; Kanis et al., 1988; Prusa et al., 1989). Solomon et al. (1988), however, observed an increase in Warner-Bratzler shear values, indicating decreased

tenderness, in muscles from pigs treated with PST when compared to controls. These researchers suggested that the observed reduction in subcutaneous fat in the PST treated pigs may lead to an increase in cold-shortening. Solomon et al. (1989) indicated that the observed decrease in tenderness in the longissimus dorsi from pigs treated with PST was due to an increase in muscle fiber area. While treatment of growing pigs did increase muscle fiber size, the percentage of muscle fiber types was not altered. This is in agreement with Beermann et al. (1990) where semitendinosus muscles from pigs treated with PST had greater cross-sectional area of muscle fibers. In this study, however, Instron shear forces were not related to PST treatment.

Sensory evaluation has also been utilized to determine the effects of PST on pork quality. PST has had no effect on initial juiciness, sustained juiciness, and pork flavor (Prusa et al. 1989a; Kanis et al. 1988; Novakofski et al. 1987). Boneless rib chops from pigs treated with 4 mg (Boles et al. 1990) and 8 mg (Prusa et al., 1989a) of PST daily were determined to be less tender than controls by trained sensory panels. Beermann et al. (1988) recognized a reduction in tenderness and juiciness between control muscles and muscles from pigs supplemented with 60 μg PST per kilogram body weight per day. This observation is interesting because no tenderness differences were detected between control muscles and muscles from pigs treated daily with 30 or 90 μg PST per kilogram body weight. Prusa (1990a) reported results from a consumer panel that indicated

consumers prefered the tenderness, juiciness, and pork flavor of loin chops from PST treated pigs when compared to chops from control pigs.

Ender et al. (1989a) and Mourot (1990) observed an increase in polyunsaturated fatty acids in subcutaneous fat from pigs treated with PST. Additionally, intramuscular lipid in rib chops from PST treated pigs had a slightly less saturated fatty acid profile (Prusa et al., 1989a). Fresh pork with a more highly unsaturated fatty acid profile may have less acceptable pork flavor and texture (Bergkamp et al., 1970). Comparisons of fresh pork with altered fatty acid compositions due to diet have illustrated some of the potential effects fatty acid profile may have on fresh pork quality.

Prusa et al. (1989a) found that rib chops from PST produced pigs had a higher concentration of unsaturated fatty acids than rib chops from controls. Sensory attributes of rib chops in the same study however were not significantly altered by PST treatment.

Rhee et al. (1990b) found that a swine ration including high oleic acid sunflower oil significantly increased the ratio of monounsaturated to saturated fatty acids in both raw and cooked loin chops and semitendinosus roasts. This was attributed to an increase in oleic acid and a concomititant decrease in myristic, palmitic, and stearic acids. Polyunsaturated fatty acids were similar between control and experimental loins and semitendinosus roasts. Raw and cooked chops and roasts within treatment groups had similar fatty acid profiles indicating no preferential loss of specific fatty acids

during cooking. Sensory evaluation of loin chops revealed similar juiciness, muscle fiber tenderness, and overall tenderness scores between treatment groups. Roasts from pigs fed high oleic sunflower oil were less resistant to shearing than controls. Sensory flavor parameters were not significantly different between treatment group. TBA-reactive substances in experimental cooked chops and roasts stored at 4° C were significantly lower than controls. This apparent inconsistency was explained by possible existence of natural anti-oxidants in the sunflower ration.

Skelley et al. (1975) reported an increase in monounsaturated and polyunsaturated fatty acids in longissimus dorsi muscles from pigs fed whole soybeans when compared to controls (soybean meal). This increase in the concentration of unsaturated fatty acids was not related to flavor scores in longissimus dorsi chops at one or four months storage. In contrast, Bergkamp et al. (1970) reported longissimus muscles from pigs fed whole roasted soybeans had lower taste panel acceptance scores than controls.

Results from these studies have indicated that an increased concentration of unsaturated fatty acids does not alter fresh pork quality. Therefore, an an increase in the levels of unsaturated fatty acids in intramuscular fat due to PST (Prusa et al., 1989a), may not alter fresh pork quality or sensory attributes.

Effects of PST and Diet on Processed Product Characteristics

PST treatment at 0, 1.67, 3.33, 5.0, and 6.67 mg/day was not related to boneless ham yield, color, or color retention (Prusa et al., 1990b). Additionally, composition of fat, moisture, and protein in boneless ham. was not altered by PST treatment at any level. Sensory evaluation of boneless hams from pigs treated with 0. 3.33, or 6.67 mg/PST/day revealed no significant differences in juiciness, tenderness, or cured flavor due to treatment. Kuecker et al. (1990) reported that PST treatment did not alter color or adversely affect sensory characteristics of boneless ham.

Canadian-style bacon from pigs treated with 0, 3.33, or 6.67 mg/PST/day were similar in proximate composition (Prusa et al., 1990b). Canadian-style bacon decreased in initial and overall tenderness as PST dose increased. No difference in Warner-Bratzler shear values, however, could be attributed to PST administration.

Reagan et al. (1990) found that frankfurters formulated with pork from PST treated animals were more springy than controls. Sensory evaluation identified frankfurters in the PST treatment group to be equal to or superior to those formulated with control pork.

Prusa et al. (1990b) found that bacon processing yields were not related to PST treatment. Bacon lean color evaluation over a sixteen week period did not identify differences due to PST treatment.

Ender et al. (1989a) observed an increase in polyunsaturated fatty acids in subcutaneous fat from pigs treated with PST. Additionally, intramuscular lipid in rib chops from PST treated pigs had a slightly less saturated fatty acid profile (Prusa et al., 1989a). Processed pork with a more highly unsaturated fatty acid profile may have less acceptable pork flavor (Rhee et al., 1988b) and texture (Shackelford et al., 1990c). Comparisons of processed pork with altered fatty acid compositions due to diet help develop an understanding of some of the potential consequences a more unsaturated fatty acid profile may have processed pork characteristics. Shackelford et al. (1990b) found that canola oil significantly increases polyunsaturated fatty acid content in boneless hams when compared to dietary treatments of animal fat, sunflower oil, safflower oil and controls. Off-flavors were reported most frequently in the boneless hams in the canola oil treatment group. Sensory scores for flavor and overall palatability were similar among all treatment groups. Warner-Bratzler shear values were not related to fatty acid composition. Visual sensory panels revealed no difference in lean color, uniformity, and firmness due to dietary treatment or fatty acid content.

Skelley et al. (1975) compared hams from pigs fed soybeans and controls fed soybean meal. Inclusion of whole roasted soybeans increased oleic, and linoleic acids in cured smoked hams. This altered fatty acid composition was not related to ham flavor, tenderness, or Warner-Bratzler shear values. Olson et al. (1973) reported canned

hams from pigs fed whole roasted soybeans had higher sensory scores for flavor and overall acceptability when compared to controls. Experimental hams had higher TBA values than controls but these values were not related to sensory scores. Cooked and raw restructured pork chops from pigs fed high oleic sunflower oil contained higher concentrations of oleic and lower concentrations of palmitic and stearic acid than control chops (Rhee et al., 1990a). Fatty acid profiles of cooked and raw chops within treatment groups were similar, therefore indicating that no preferential loss of unsaturated fatty acids during cooking of restructured chops was observed. Furthermore, TBA values were not related to dietary treatment or fatty acid composition.

Rhee et al. (1988b) found that ground pork from pigs fed canola oil contained higher concentrations of oleic, linoleic, and linolenic acids than control ground pork which contained greater concentrations of stearic and palmitic acids. Ground pork in the canola group displayed increased succeptability to lipid oxidation than controls. This increased oxidation could not be attributed to microsomal enzyme lipid peroxidation activity, heme pigment content, non-heme iron content, or total lipid concentration. The tendency of lipid oxidation in the canola oil group was therefore attributed to the increased concentration of polyunsaturated fatty acids. Rhee et al. (1990a) found that ground pork from animals fed a high oleate sunflower ration had greater concentrations of oleic acid than controls. Experimental raw ground pork had lower TBA values

than controls. Therefore, it may be concluded that an increase in the level of polyunsaturated fatty acids may increase lipid oxidation potential in ground pork, but an increase in monounsaturated fatty acids may not.

Shackelford et al. (1990d) compared fresh sausage from pigs fed either sunflower, canola, safflower oils, animal fat or soybean meal (the control). All dietary treatments increased oleic and linoleic acid content and decreased myristic, palmitic and stearic acid content when compared to controls. High oleate and linoleate concentration in sausage formulated at thirty percent fat decreased springiness and was found to be "too mushy" by a trained sensory panel. Sausage from the canola oil group contained greater concentrations of linoleic acid and scored significantly lower in palatability than controls and remaining experimental groups. Low fat (fifteen percent fat) sausage in all treatment groups were similar in springiness and overall palatability indicating that an acceptable high oleate, low fat sausage could be manufactured.

An increase in oleic and linoleic acid in pork sausage due to dietary roasted soybeans was not related to sausage flavor (Skelley et al., 1975). This is consistent with Olson et al. (1973) where a whole soybean ration increased iodine number but was not related to flavor, overall acceptability, or peroxide number in pork sausage.

Skelley et al. (1975) found that pigs fed roasted soybeans had higher levels of oleic and linoleic acids in subcutaneous and intramuscular fat when compared to pigs fed soybean meal. Bacon

cooking yields and sensory flavor scores were not related to diet or level of saturation. Shackelford et al. (1990a) compared the effects of dietary animal fat, sunflower, safflower, and canola oils on bacon acceptability. Bacon from the canola and sunflower oil groups had increased cooking yields over controls and remaining experimental groups. Skillet yield was not affected by growing ration. Canola oil increased linoleic and linolenic acids when compared to controls and remaining experimental groups. Bacon from the canola oil group was identified by a trained taste panel as having the lowest overall palatability and the highest incidence of off-flavors. Consumer panels revealed similar findings The increased incidence of off-flavors was attributed to derivatives of linolenic acid.

Ziprin et al. (1990) compared a soybean meal diet to one containing high oleic sunflower oil. Cooked bacon from the sunflower group contained significantly greater levels of oleic acid without an increase in polyunsaturated fatty acids. Cooking yields were not significantly different between control and experimental groups. Cooked and raw bacon showed no difference in TBA-reactive substances that could be attributed to diet or fatty acid composition. This suggested that an increase in monounsaturated fatty acids (specifically oleic acid) did not increase the lipid oxidation potential in bacon. The bacon from the high-oleate ration group contained a significantly higher concentration of residual nitrite. This was attributed to nitrite reacting with the more plentiful unsaturated carbon bonds. It was suggested that a higher concentration of

residual nitrite could increase the potential for the production of nitrosamines.

Leszczynski et al. (1990) reported that short-term feeding of full fat soybeans increased bacon polyunsaturated:saturated fatty acid ratios. This increased concentration of polyunsaturated fatty acids in bacon was not related to TBA values. Additionally, the increased level of polyunsaturated fatty acids did not alter the bacon slicing characteristics.

Sensory evaluation for crispiness, flavor, and overall palatability in bacon from pigs fed roasted soybeans were similar to bacon from the control soybean meal group (Olson et al., 1973). Fat from the experimental group had higher iodine values, indicating that the dietary treatment did increase the level of usnsaturated fatty acids.

St. John et al. (1986) produced frankfurters from a beef and pork blend using pork trimmings from sorghum (control) or canola oil fed pigs. Frankfurters in the canola oil group contained lower levels of saturated fatty acids and greater concentrations of linoleic acid than controls. Frankfurters with the more unsaturated fatty acid composition had greater processing yields than controls. Textural profiles determined that the control frankfurters were less cohesive than experimental frankfurters. Frankfurters produced with pork trimmings in the canola oil treatment group had significantly greater reports of off-flavors by a trained sensory panel. TBA values, however, were not related to dietary treatment. In contrast, Olson et

al. (1973). determined that a whole roasted soybean ration was not related to frankfurter sensory flavor, texture, or juiciness values.

Shackelford et al. (1990c) evaluated properties of fermented summer sausage produced with pork from pigs fed soybean meal (control), animal fat, canola oil, sunflower oil, and safflower oil. Summer sausage in the sunflower group contained the highest concentration of oleic acid while dietary canola oil increased linoleic concentration more than all other treatments. Control summer sausage contained the greatest concentration of myristic, palmitic and stearic acid. Sensory comparisons revealed that control, high fat (25 percent) sausage had significantly greater scores for springiness, texture, and overall palatability than all experimental groups. All of the high fat sausage from the oil treatment groups were found to be "too mushy" when compared to controls and animal fat treatments . The negative affects of the oil treatments on the high fat products were significantly reduced in the low fat (fifteen percent) summer sausage. Sensory flavor and TBA values were not related to dietary treatment.

Results from these studies have indicated that an increase in monounsaturated fatty acids does not affect textural or flavor characteristics in processed pork quality. An increase in polyunsaturated fatty acids, however, may increase lipid oxidation, production of off flavors and decrease textural integrity. If PST administration increases polyunsaturated fatty acid concentration in

subcutaneous (Ender et al., 1989a) similar problems may arise in processed pork products from PST treated pigs.

SECTION I. EFFECTS OF PORCINE SOMATOTROPIN (PST) ADMINISTRATION TO GROWING PIGS ON ADIPOSE TISSUE COMPOSITION AND PROCESSED PRODUCT CHARACTERISTICS

Effects of Porcine Somatotropin (PST) Administration to Growing Pigs on Adipose Tissue Composition and Processed Product Characteristics

S. M. Lonergan, J. G. Sebranek, K. J. Prusa and L. F. Miller
215 Meat Laboratory, Iowa State University, Ames, IA 50011 (515)-294-1091

Author Lonergan is with the Animal Science Department, Iowa State University. Author Sebranek is with the Departments of Animal Science and Food Science and Human Nutrition, Iowa State University. Author Prusa is with the Department of Food Science and Human Nutrition, Iowa State University. Author Miller is with Pitman-Moore Inc., Box 207, Terre Haute, Indiana, 47808.

Running Head - Effect of PST on processed pork quality

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ABSTRACT

Fatty acid profiles and proximate composition were examined at seven carcass locations from 64 pigs. Fatty acid composition was not altered by PST treatment. The more unsaturated outer layer of subcutaneous fat was present in a greater proportion in the PST-treated pigs. Adipose tissue fat content was decreased, whereas percentage moisture and protein was increased, by PST. Boneless ham characteristics did not differ among treatment groups. Pepperoni from PST pigs dried more efficiently and was harder than control pepperoni. Bacon from PST pigs contained less fat and was softer than control bacon. Difference in texture of products from PST-treated pigs seemed to be a result of an altered proximate composition.

INTRODUCTION

An increase in consumer demand for lean meat products has increased the interest in efficient production of lean pork. It has been long held that porcine somatotropin, a naturally occurring peptide hormone, promotes pig growth and decreases carcass fat content (Machlin, 1972). With the use of existing recombinant DNA techniques, porcine somatotropin can be produced in mass quantity. The potential for use of porcine somatotropin (PST) in the pork production industry has been enhanced by this increased supply of PST. Daily administration of PST to growing pigs increases average daily gain (Johnson et al., 1989) and feed efficiency (Ender et al., 1989). Carcasses from pigs treated with PST had less average backfat (Evock et al., 1988) and increased lean as evidenced by greater loin eye area (Prusa et al., 1990) and yield of primary cuts (Ender et al., 1989). Additionally, intramuscular fat in rib chops was reduced by PST treatment (Prusa et al., 1989a). The beneficial effects of PST treatment have been accompanied by few consistent alterations in fresh pork quality (Prusa et al.,1989b).

Although there is much information available concerning the effects of PST on lean pork production, little information is available on the processing characteristics of pork as a result of PST treatment. It has been reported that subcutaneous fat from PST-treated pigs is higher in polyunsaturated fatty acids than fat from controls (Ender et al., 1989). An additional report indicated that intramuscular lipid

from pigs treated with PST was more unsaturated than that from controls (Prusa et al., 1989a). Pork with a more polyunsaturated fatty acid composition may lead to less acceptable processed pork flavor (Rhee et al., 1988) and/or texture (Shackelford et al., 1990).

Given the success of PST administration in achieving efficient production of lean pork, it may become a common practice in the pork production industry. Because a great proportion of the pork carcass is utilized in processed products, it is important to investigate the characteristics of processed pork products from pigs treated with PST. Therefore, the objectives of this study were: 1) to determine the effect of PST treatment of growing pigs on fatty acid composition of porcine adipose tissue and 2) to determine the effect of PST treatment on boneless ham, bacon and pepperoni characteristics.

MATERIALS AND METHODS

Ten barrows and 22 gilts were administered a 4-mg/day supplement of PST beginning at 54 kg live weight to a final live weight of 108 kg. Eighteen barrows and 14 gilts served as controls and received no injections. All pigs were slaughtered at the Iowa State University Meat Laboratory. Tenth-rib fat depth measurements were recorded as total depth and as depth of the outer, middle and inside layer of subcutaneous fat. Adipose tissue samples were collected at the following carcass locations:

1. Outside layer of subcutaneous fat over the tenth rib region
2. Middle layer of subcutaneous fat over the tenth rib region
3. Inside layer of subcutaneous fat over the tenth rib region
4. Outside layer of subcutaneous fat over the triceps brachii
5. Outside layer of subcutaneous fat at the navel edge of the belly
6. Outside layer of subcutaneous fat over the biceps femoris
7. Internal leaf fat

Leaf fat samples were collected during carcass dressing. Subcutaneous fat samples were taken during carcass fabrication 24 hr postmortem. Layers of subcutaneous fat were separated at the visible connective tissue interface between layers. Samples were vacuum-packaged in high-oxygen-barrier bags and stored at -30°C until analysis.

Adipose Tissue Composition

In preparation for chemical analysis, adipose tissue samples were ground and homogenized for 90 sec in a Robot Coupe R301 Ultra food processor (Robot Coupe, Jackson, MS). Fatty acid methyl esters were prepared according to a direct transesterification method described by Lepage and Roy (1986). Fatty acid methyl esters were prepared according to a direct transesterification method described by Lepage and Roy (1986). Triplicate samples of adipose tissue in 125 mg aliquots were weighed directly into 20 ml borosilicate glass tubes that had been rinsed with a chloroform : methanol (2:1, v/v) solvent. Two ml of methanol:benzene (4:1, v/v) was delivered directly to each sample. Tubes were capped with teflon lined screw caps and vortexed in a Super Mixer (Curtin Matheson Scientific Houston TX) for five seconds. 200 µl of acetyl chloride was delivered to the mixed slurry with an Eppendorf Pipet. Individual sample tubes were gassed with nitrogen and capped. Tubes were placed in a water bath (Precision Scientific Group, Chicago IL) set at 100° C. Samples were allowed to reflux for 60 minutes. Tubes were then removed from the water bath and allowed to cool at room temperature. Five ml of 6 percent K_2CO_3 and 2 ml additional benzene were added to each tube. Individual samples were vortexed in a Super Mixer (Curtin Matheson Scientific, Houston TX) for 5 seconds. Samples were centrifuged for 10 minutes at 3000 rpm in a Beckman Model J-21C centrifuge (Beckman Instruments Inc., Palo Alto, CA) to separate the benzene layer (which contained the fatty acid methyl

esters) from the methanol layer. Two µl samples for chromatographic separation were taken from the benzene layer and delivered to the injection port using a 10 µl Hamilton Microliter 700 Series syringe (Hamilton Co., Reno, Nevada).

A Waters Dimension I Gas Chromatograph (Millipore, Ventura, CA) equipped with a flame ionization detector was used with a 30-m fused silica capillary column (internal diameter of 0.25µm, J & W. Scientific, Folsom, CA) to separate the fatty acid methyl esters. Operating conditions were as follows: helium carrier gas 20 cm/sec, inlet and detector temperature at 220°C, initial oven temperature was 170°C and increased to 203° C at a rate of 2.5°C per min. Fatty acid methyl esters were identified by comparison with methyl ester standards (Sigma Chemical Co., St. Louis, MO). The proportion of each fatty acid present was calculated by integration of the area under the peak by using the Waters Dynamic Solutions Maxima 820 Chromatography Workstation (Millipore, Ventura, CA).

Proximate analysis of the adipose tissue was determined by AOAC approved methods (AOAC, 1980).

Boneless Ham Production and Evaluation

Short shank hams were deboned and trimmed to remove as much seam fat and connective tissue as possible. Hams were frozen until further processing.

Batches of 11.0-kg boneless hams were pumped to slightly below the 25 % target by using a Townsend Model 1400 injector (Townsend Engineering Inc., Des Moines, IA). Additional brine was

added to the tumblers to result in a 25% brine addition. Brine composition was 36.4 kg water, 5 kg salt, 3 kg sugar, 1 kg phosphate blend (sodium tripolyphosphate and sodium phosphate, glassy), 28.3 g sodium nitrite and 99.8 g sodium erythorbate.

After pumping, the hams were mascerated and placed in separate tumblers (by treatment) and tumbled for 18 hr at 10 min on / 50 min rest sequence. After tumbling was complete, hams were stuffed into large-diameter prestuck fibrous casings.

Hams were smoked and cooked in an Alkar smokehouse equipped with a direct digital control system (Alkar, Lodi, WI) to an internal temperature of 68°C. Cooking procedure processing yields were determined by calculating cooked weight as a percentage of pumped weight.

Proximate analysis was determined by using AOAC approved methods (AOAC, 1980). Color measurements were made using the HunterLab Labscan Spectrophotometer (Hunter Associated Laboratories Inc., Reston, VA) reflectance using daylight as a light source. Reflectance values for "L" (lightness), "a" (greeness-redness) and "b" (blueness-yellowness) were measured to determine color (Koivistoinen and Loukimo, 1969). The instrument was standardized with a white tile [X = 81.60, Y = 86.68, Z = 91.18 (Equivalent to L = 93.10, a = 1.15, b = 1.26)], and 10 samples per treatment were measured.

An Instron Model 4502 (Instron Corp., Canton, MA) equipped with a Warner-Bratzler Shear attachment was used to make textural

measurements. A 10-kN load cell was used with a crosshead speed of 100 mm per min Data acquisition, executed at a rate of 1 data point per 0.10 sec, and integration were performed by LabVantage DB Series XII software (Instron Corp., Canton, MA). Results were expressed as the force required to shear 18-mm cores of boneless ham. Three measurements from each of 10 samples per treatment were made.

Pepperoni Production and Evaluation

Boneless pork picnic shoulders and belly trimmings from each treatment group were ground through a 1.27 cm plate and analyzed for moisture, protein and fat using AOAC approved methods (AOAC, 1980).

Formulation target for the 11.5-kg meat block was 20% fat from use of the ground picnics and belly trimmings. Nonmeat ingredients were added as follows: 90.8 g dextrose, 22.7 g Modern cure (Heller Seasoning and Ingredients Inc., Bedford Park, Il), 15.0 g ground pepper, 5.0 g whole fennel seed, 54.5 g paprika oleoresin flavoring (Diversitech Inc., Alachua, FL), a lactobacillus starter culture (Microlife Technics, Sarasota, FL) and 250.6 g salt. The product was mixed, ground through a 0.50-cm plate and stuffed into a 3.8 cm fibrous casing. After an 18 hour fermentation at 27°C and 96 % relative humidity in an Alkar enviromental chamber (Alkar, Lodi, WI) the product was smoked in an Alkar smokehouse equipped with a direct digital control system (Alkar, Lodi, WI). The drying

conditions in an environmental chamber (Alkar, Lodi, WI) were 12.7°C and 78 % relative humidity for 15 days. Drying conditions were controlled and monitored by a direct digital control system (Alkar, Lodi, WI). Finished dry-product yield was determined as a percentage of fresh product weight.

Product moisture and protein concentrations were measured by using AOAC approved methods (AOAC, 1980). Textural analysis was evaluated by measuring the force to compress a stick of pepperoni 30 % of the diameter of the sausage with an Instron model 4502 equipped with a 10-kN load cell (Instron Corp., Canton, MA). Instron conditions for the one cycle compression were: 100 mm per min crosshead speed and a preload of 0.5 kg. Hardness of a slice of pepperoni was measured as the force necessary to break or puncture a 0.2-cm slice of pepperoni. Instron conditions for a one-cycle break utilizing a 100-N load cell were: 100 mm per min crosshead speed and a 0.025-kg preload. Data acquisition, executed at a rate of 1 data point per 0.05 sec, and integration were performed by LabVantage DB Series XII software (Instron Corp., Canton, MA). Three measurements per stick were measured for stick textural parameters and five slices per stick were measured for slice hardness.

Bacon Production and Evaluation

Raw bellies (IMPS 408) from six treated and six control pigs were obtained as paired bellies for bacon evaluation. Six treated and six control bellies (one of the paired bellies) were ground and

analyzed for moisture, protein and fat by using AOAC approved methods (AOAC, 1980).

The other belly of each pair was pumped to a 15 % target level with a Townsend 1400 injector (Townsend Engineering Inc., Des Moines, IA). Brine composition included 30.8 kg water, 8 kg salt, 4.8 kg sugar, 1.6 kg phosphate blend (sodium tripolyphosphate and sodium phosphate, glassy), 45.3 g sodium nitrite and 159.7 g sodium erythorbate. After injection, bellies were allowed to equilibrate at 3.3°C.

Smoking and heat processing of the bellies were done in an Alkar smokehouse (Alkar, Lodi, WI) to a final endpoint temperature of 54 °C. Chilled weights were used to calculate thermal processing yield based on the pumped weights. Composition was determined using AOAC methods (AOAC, 1980).

An Instron Model 4502 (Instron Corp., Canton, MA) equipped with a 10-kN load cell was used to measure bacon slab textural parameters. Instron conditions for the two-cycle compression were: 100 mm per min crosshead speed and a 0.70-kg preload. Hardness was determined using the force necessary to compress a slab of bacon 25 % of the thickness of the slab at 50 % of th length of the belly from the shoulder end. Springiness was determined by measuring the recovery of the slab after the first compression. Three compressions at 25, 50 and 75 percent of the width from the navel edge of the bacon were completed. Data acquisition and integration for textural analysis was performed by LabVantage DB Series XII software

(Instron Corp., Canton, MA). Bacon slab thickness was measured at 50 % of the length of each belly from the shoulder end.

Statistical Analysis

Adipose tissue composition data was analyzed in a split-plot design as outlined by Steel and Torrie (1980). Least-square means were separated using Duncans least significant difference method (Steele and Torrie, 1980). An alpha of 0.05 was chosen as a level of significance. Processed product data were analyzed with a completely random design. Three production replications were conducted for the boneless ham, bacon and pepperoni. An alpha of 0.05 was chosen as a level of significance. The Statistical Analysis System (SAS, 1985) was used to compute least-squares means, standard errors and analysis of variance.

RESULTS AND DISCUSSION

Treatment with PST resulted in a 40 % reduction of 10th-rib fat (Table 1). This is a greater response than reported by Prusa et al. (1990) where PST treatment decreased average backfat by 18 %. Etherton (1988), however, reported up to a 68 % reduction in carcass lipid in response to PST treatment. PST treatment decreased fat deposition in the outer layer of 10th-rib fat by 30 %, the middle layer by 45 % and the inner layer by 53 %. This indicated that the inner layer of fat was the most metabolically active during the finishing stage and that PST was most effective in reducing the lipid accretion at this location. Anderson and Kauffman (1973) reported that the outer layer of subcutaneous fat over the 10th thoracic vertebrate was the earliest developing and had the greatest activity of lipogenic enzymes during the first 3.5 months of age. The middle and inner layers had the greatest activity of lipogenic enzymes and, consequently, the greatest amount of development after 3.5 months of age. These observations may explain the difference in the degree to which 10th-rib fat was reduced by PST.

Gilts had significantly less total fat depth at the 10th-rib than barrows ($P < 0.01$). No significant difference in the outer or inner layer fat depth between gilts and barrows was observed ($P > 0.05$) but gilts had significantly less fat depth at the middle layer than barrows ($P < 0.05$). The sex by PST treatment interaction for 10th-rib fat was not

significant. Campbell et al. (1989) also reported that gilts and barrows responded similarly to PST treatment.

Adipose tissue composition

Adipose tissue from gilts had a more unsaturated fatty acid profile than barrows for all locations (Table 2). Adipose tissue from barrows contained higher concentrations of palmitic (C16:0) and stearic (C18:0) acids and a lower concentration of oleic acid (C18:1) than gilts at all locations. Villegas et al. (1973) also observed that adipose tissue from barrows contained significantly greater concentrations of stearic and palmitic acids than did gilts. Subcutaneous fat over the triceps brachii, belly and biceps femoris from barrows contained a significantly greater concentration of myristic acid (C14:0) than those of gilts. No significant difference in linoleic acid (C18:2) due to sex was observed in the three layers of 10th-rib fat. In contrast, Koch et al. (1968) reported that subcutaneous backfat from gilts contained a significantly greater concentration of linoleic acid than barrows. Geri et al. (1990) also reported that subcutaneous fat from gilts contained significantly greater concentrations of polyunsaturated fatty acids than barrows. Belly fat from gilts did contain significantly greater levels of linoleic acid than barrows. Martin et al. (1972), however, reported that belly fat from gilts contained significantly less linoleic acid than belly fat from barrows. Leaf fat from gilts contained significantly greater levels of linoleic and linolenic acid (C18:3) than did leaf fat from

barrows. Koch et al. (1968) also reported a greater concentration of polyunsaturated fatty acids in leaf fat from gilts.

Considerable difference in fatty acid composition due to carcass location was observed (Table 3). Adipose tissue from the outside layer of 10th-rib fat had a significantly greater concentration of total unsaturated fatty acids than the middle layer of 10th-rib fat, which in turn had a greater concentration of unsaturated fatty acids (specifically linoleic and linolenic acids) than the inner layer. This is consistent with results reported by Koch et al. (1968) and Villegas et al. (1973). Leaf fat was the greatest source of saturated fatty acids and also had significantly less unsaturated fatty acids than adipose tissue from all subcutaneous locations. The outer layer of 10th-rib fat was less saturated than the outer layer of belly fat but was more saturated than the outer layer of subcutaneous fat over the triceps brachii. No significant differences in total saturated or unsaturated fatty acids were observed between the outer layer of 10th-rib fat and outer layer of fat over the biceps femoris.

Adipose tissue fatty acid composition was not significantly altered by PST treatment at any location with the exception of a lower concentration of oleic acid in belly fat sampled from the PST treatment group (Table 4). In contrast, Ender et al. (1989) reported that subcutaneous fat from PST-treated pigs had a greater concentration of unsaturated fatty acids (primarily linoleic acids) than fat from control pigs. Additionally, Mourot (1990) determined that backfat from pigs that received daily injections of PST, compared with

the control counterparts, had a slightly more unsaturated fatty acid profile with higher concentrations of linoleic and linolenic acids. The inconsistency between previous findings and the results of our study may be a result of the sampling method for subcutaneous fat. The depth of the middle and inside layers of 10th-rib fat were reduced to a greater degree than the outside layer, which possessed a more unsaturated fatty acid profile including a greater concentration of linoleic and linolenic acids. Therefore, although the single layers of subcutaneous fat did not differ in fatty acid composition due to PST treatment, the greater reduction of fat layers with a more saturated fatty acid composition could result in a greater overall proportion of unsaturated fatty acids in samples that include all three layers of subcutaneous fat. The more unsaturated outer layer of subcutaneous fat represents a larger percentage of the total 10th-rib fat depth in the PST-treated pigs.

Moisture (Figure 1) and protein (Figure 2) contents in adipose tissue from PST-treated pigs were significantly higher than in controls within each location ($P < 0.01$). A significant treatment by location interaction was observed for both moisture ($P < 0.01$) and protein ($P < 0.01$). A 101 % increase in moisture due to PST treatment was observed in the outer layer of fat over the triceps brachii and leaf fat. In the inner layer of 10th-rib fat, PST treatment increased moisture content by 70 %. PST treatment increased protein content in the outer layer of fat over the triceps brachii by 79 % and increased protein content in the inner layer of 10th-rib fat by 50 %. Kramer et al.

(1990) also found that PST treatment increased moisture and protein content of adipose tissue sampled immediately before slaughter. Because PST decreases lipogenesis (Walton and Etherton, 1986), it is likely that the increase in moisture and protein is a result of an increase in extracellular space in the adipose tissue due to a smaller adipocyte size. Ether extractable fat (Figure 3) was significantly decreased by PST treatment ($P < 0.01$). This demonstrates the effect of PST treatment in the reduction of lipid accretion. A treatment by carcass location interaction was determined to be significant ($P < 0.01$). PST treatment decreased ether extractable fat content by 20.5 % in the subcutaneous fat over the triceps brachii and extractable lipid in the leaf fat was decreased by only 7 %. These results are consistent with the report of Kramer et al. (1990) where ether extractable fat in adipose tissue was significantly decreased by PST treatment. The data presented here suggest that concerns of a softer subcutaneous fat (Ender et al., 1989) from PST-treated pigs may be a result of a higher moisture content rather than an altered fatty acid profile.

Boneless Ham

Moisture and protein contents of boneless ham were not altered by PST treatment (Table 5). PST treatment slightly decreased fat content in boneless hams, but this difference was not significant ($P > 0.05$). Hams from control pigs had a greater, though not significant, smokehouse yield than hams from PST-treated pigs ($P > 0.05$). Warner-Bratzler shear values did not differ due to PST treatment.

Prusa et al. (1990) also reported no differences in Warner-Bratzler shear values or sensory tenderness attributes in boneless ham due to PST treatment. There were no differences among treatments in objective color measurements of the hams for lightness, redness or yellowness. This is in agreement with Kuecker et al. (1990).

Pepperoni

Pepperoni composition before drying was not affected by PST treatment (Table 6). Pepperoni in the PST-treated group after 15 days of drying had a significantly higher protein content ($P < 0.01$), and a significantly lower moisture:protein ratio ($P < 0.05$). Moisture composition in the fresh product was slightly higher, and dry product moisture slightly lower, in the PST treatment group. Although this was the trend in every replication, these differences were not significant ($P > 0.05$). In data not shown, PST treatment did not alter the pH of the fresh or fermented pepperoni. These data suggest that pepperoni formulated with PST-produced pork dried more efficiently and therefore reached a moisture:protein ratio of 1:1.6 approximately 1 day earlier than the control pepperoni. This may be due to the slightly lower, though not significant, crude fat content in the original formulation of the pepperoni in the PST-treated group. This small difference in fat content may have been enough to facilitate more efficient migration of the moisture from the interior to the surface of the product (Palumbo and Smith, 1983). If the pepperoni formulated with pork from PST-treated pigs does actually dry more efficiently, it

may be necessary to slow the initial drying rate to avoid case hardening. Percentage yield was lower ($P < 0.05$) in the PST-treated group. This would be expected because the moisture:protein ratio was lower than that of controls ($P < 0.05$). Pepperoni in the PST treatment group had higher hardness values for both the sausage stick ($P < 0.01$) and slice ($P < 0.01$). This may be a result of the lower moisture:protein ratio in the finished PST product. In a comparison of commercially available pepperoni, pepperoni with lower moisture:protein ratios were significantly harder than pepperoni with a higher moisture and lower protein content (Lonergan, unpublished data). Therefore, the differences observed in textural hardness may be a result of the lower moisture:protein ratio in the PST treatment group.

Bacon

Bellies from PST-treated pigs contained significantly more moisture ($P < 0.01$), and protein ($P < 0.01$) and less crude fat ($P < 0.01$) than bellies from control pigs (Table 7). Bacon from the PST-treated pigs was also higher in moisture, ($P < 0.01$) and protein ($P < 0.01$) and lower in fat ($P < 0.01$) than controls. although it may be anticipated that bacon in the PST treatment group would be lower yielding because of a higher moisture content in the fresh bellies, chilled yield was not significantly altered by PST treatment ($P > 0.05$). This is consistent with Prusa et al. (1990). Bacon slabs from control pigs required a significantly greater force ($P < 0.05$) for compression and were more springy ($P < 0.01$) than bacon in the experimental group.

This may be attributed to the elevated moisture content in the experimental bacon. Bacon thickness was significantly greater ($P < 0.01$) in the control group. This also may have contributed to the springiness of the control bacon. As stated earlier, subcutaneous adipose tissue from the midline of the belly of PST-treated pigs contained more moisture than did controls (Figure 1). Therefore, the separable fat in the bacon may also have contained more moisture and been less resistant to compression and displayed less springiness.

CONCLUSIONS

PST treatment did not alter the overall fatty acid saturation in subcutaneous or perirenal fat depots, but PST treatment did result in a greater reduction of the more saturated middle and inner layers of subcutaneous fat over the 10th-rib. The more unsaturated outer layer of subcutaneous fat is then present in a greater proportion in the PST-treated pigs. This may explain previous reports of differences in fatty acid saturation as a result of PST treatment. PST treatment increased moisture and protein content and decreased crude fat content in all adipose tissue depots sampled. The compositional effect is likely to alter some processing characteristics as observed in this study. These included bacon texture and pepperoni drying characteristics. Boneless hams in this study were not affected by PST treatment. Textural differences in processed products made from PST produced pork, when observed, probably are due to proximate composition changes rather than altered fatty acid profiles.

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Table 1. Tenth-rib fat depth of control pigs and pigs treated with PST [a]

	Outer Layer	Middle Layer	Inner Layer	Total Fat Depth
By Treatment				
CONTROL	0.96[b]	0.77[b]	0.30[b]	2.03[b]
PST-Treated	0.65[c]	0.41[c]	0.14[c]	1.20[c]
By Sex				
BARROWS	0.81	0.64[d]	0.22	1.67[d]
GILTS	0.81	0.54[e]	0.21	1.56[e]

a Fat depth means are reported in centimeters.

b-c Treatment group fat depth means with different superscripts are significantly different due to PST treatment ($P < 0.01$).

d-e Sex group fat depth means with different superscripts are significantly different due to sex ($P < 0.05$).

Table 2. Fatty acid composition of adipose tissue at seven carcass locations from barrows and gilts[a]

Fatty	LOCATION														
	OUTSIDE		MIDDLE		INSIDE		TRICEPS		BELLY		BICEPS		LEAF		SEM[f]
Acid[b]	Barr.	Gilt	Barr.	Gilt	Barr.	Gilt	Barr.	Gilt	Barr.	Gilt	Barr.	Gilt	Barr.	Gilt	
C14:0	1.33	1.30	1.30	1.25	1.37	1.33	1.41[d]	1.32[e]	1.47[d]	1.36[e]	1.40[d]	1.31[e]	1.52	1.50	0.03
C16:0	24.7[d]	23.9[e]	25.7[d]	25.1[e]	26.5[d]	25.8[e]	25.1[d]	24.1[e]	26.2[d]	24.9[e]	25.1[d]	24.1[e]	29.3[d]	28.4[e]	0.21
C16:1	2.56	2.64	2.15[d]	2.40[e]	2.27	2.36	2.90	2.95	2.81	2.91	2.83	2.92	2.00	2.06	0.08
C18:0	13.6[d]	13.0[e]	15.2[d]	14.6[e]	15.8[d]	15.1[e]	12.7[d]	12.2[e]	14.2[d]	12.9[e]	13.5[d]	12.5[e]	20.0[d]	19.1[e]	0.19
C18:1	43.2[d]	44.5[e]	41.6[d]	42.6[e]	41.4[d]	42.3[e]	45.1[d]	46.5[e]	42.6[d]	43.6[e]	45.0[d]	46.8[e]	35.8[d]	36.5[e]	0.29
C18:2	14.1	14.0	13.5	13.5	12.3	12.6	12.3	12.5	12.2[d]	12.8[e]	11.7	12.0	10.9[d]	11.9[e]	0.26
C18:3	0.53	0.57	0.50	0.51	0.47	0.49	0.46	0.49	0.50	0.51	0.47	0.48	0.45[d]	0.51[e]	0.01
TOTAL[c]															
SAT.	39.6[d]	38.2[e]	42.1[d]	41.4[e]	43.6[d]	42.2[e]	39.3[d]	37.7[e]	41.9[d]	39.2[e]	40.0[d]	37.9[e]	50.8[d]	49.0[e]	0.29
UNSAT.	60.4[d]	61.8[e]	57.9[d]	58.6[e]	56.4[d]	57.8[e]	60.7[d]	62.3[e]	58.1[d]	60.8[e]	60.0[d]	62.1[e]	49.2[d]	51.0[e]	0.30

a Fatty acid composition is expressed as percentage of the total methyl esters.
b Carbon chain length : number of double bonds.
c Totals are reported as total saturated and unsaturated fatty acids.
d-e Means within one location with different superscripts are significantly different ($P < 0.05$) due to sex.
f SEM is the standard error of the mean.

Table 3. Fatty acid composition of porcine adipose tissue separated by carcass location[a]

	OUTER	MIDDLE	INNER	TRICEPS	BELLY	BICEPS	LEAF	SEM[k]
C14:0[b]	1.31[d]	1.31[e]	1.35[f]	1.37[g]	1.41[h]	1.35[f]	1.51[i]	0.01
C16:0	24.3[d]	25.4[f]	26.1[h]	24.6[e]	25.6[g]	24.6[e]	28.8[i]	0.07
C16:1	2.60[f]	2.28[e]	2.31[e]	2.92[h]	2.86[g]	2.89[gh]	2.03[d]	0.02
C18:0	13.2[f]	14.9[h]	15.4[i]	12.4[d]	13.6[g]	12.9[e]	19.5[j]	0.07
C18:1	44.1[g]	42.1[e]	41.9[e]	45.8[h]	43.6[f]	45.9[h]	36.2[d]	0.12
C18:2	14.1[h]	13.5[g]	12.4[f]	12.4[f]	12.4[f]	11.8[e]	11.4[d]	0.10
C18:3	0.55[g]	0.51[f]	0.48[de]	0.48[de]	0.50[ef]	0.47[d]	0.48[de]	0.01
Total[c]								
Saturated	38.9[e]	41.6[g]	42.9[h]	38.4[d]	40.6[f]	38.9[e]	49.8[i]	0.11
Unsaturated	61.1[h]	58.4[f]	57.1[e]	61.6[i]	59.4[g]	61.1[h]	50.2[d]	0.11

[a] Fatty acid composition is expressed as percentage of the total methyl esters.
[b] Carbon chain length : number of double bonds.
[c] Totals are reported as total saturated and unsaturated fatty acids.
[d-j] Means with different superscripts are significantly different due to carcass location ($P < 0.05$).
[k] SEM is the standard error of the mean

Table 4. Fatty acid composition of adipose tissue at seven carcass locations from controls and pigs treated with PST[a]

	LOCATION													
Fatty	OUTSIDE		MIDDLE		INSIDE		TRICEPS		BELLY		BICEPS		LEAF		SEM[f]
Acid[b]	CONT	PST	CONT	PST	CONT	PST	CONT	PST	CONT	PST	CONT	PST	CONT	PST	
C14:0	1.33	1.29	1.29	1.29	1.34	1.35	1.35	1.39	1.41	1.43	1.33	1.37	1.51	1.52	0.02
C16:0	24.3	24.2	25.5	25.3	26.4	25.9	24.6	24.6	25.6	25.5	24.6	24.6	29.0	28.8	0.21
C16:1	2.61	2.59	2.29	2.26	2.35	2.27	2.91	2.94	2.89	2.82	2.87	2.91	2.04	2.03	0.08
C18:0	13.1	13.4	14.9	14.9	15.3	15.5	12.4	12.6	13.4	13.8	12.8	13.1	19.5	19.5	0.18
C18:1	44.0	43.8	42.2	42.1	41.9	42.0	46.0	45.6	43.9[d]	43.2[e]	46.0	45.8	36.2	36.1	0.28
C18:2	14.1	14.1	13.4	13.7	12.2	12.5	12.3	12.4	12.2	12.7	11.9	11.8	11.3	11.5	0.25
C18:3	0.54	0.55	0.51	0.51	0.47	0.49	0.48	0.48	0.49	0.51	0.47	0.48	0.47	0.49	0.01
TOTAL[c]															
SAT.	38.8	39.0	41.7	41.5	43.1	42.7	38.3	38.6	40.5	40.8	38.8	39.0	50.0	49.7	0.28
UNSAT.	61.2	61.0	58.3	58.5	56.9	57.3	61.7	61.4	59.5	59.2	61.2	61.0	50.0	50.3	0.30

[a] Fatty acid composition is expressed as percentage of the total methyl esters.
[b] Carbon chain length : number of double bonds.
[c] Totals are reported as total saturated and unsaturated fatty acids.
[d-e] Means within one location with different superscripts are significantly different ($P < 0.05$) due to PST treatment
[f] SEM is the standard error of the mean.

Table 5. Composition, yield, shear resistance and color of boneless ham from PST-treated and control pigs [a]

	CONTROL	PST-TREATED	SEM[c]
Moisture (%)	72.83	72.99	0.12
Protein (%)	18.69	18.93	0.15
Crude Fat (%)	3.44	2.91	0.18
Percent Yield (%)	91.48	90.55	0.53
Warner-Bratzler Shear (kg)	2.18	2.31	0.10
Color[b]			
L	57.80	58.02	0.4
a	8.67	8.46	0.18
b	6.83	6.89	0.15

[a] No significant differences were observed among treatment group means ($P > 0.05$).

[b] L = Lightness, a = redness, b = yellowness.

[c] SEM is the standard error of the mean.

Table 6. Original composition, final product composition and hardness of pepperoni formulated with pork from PST-treated and control pigs

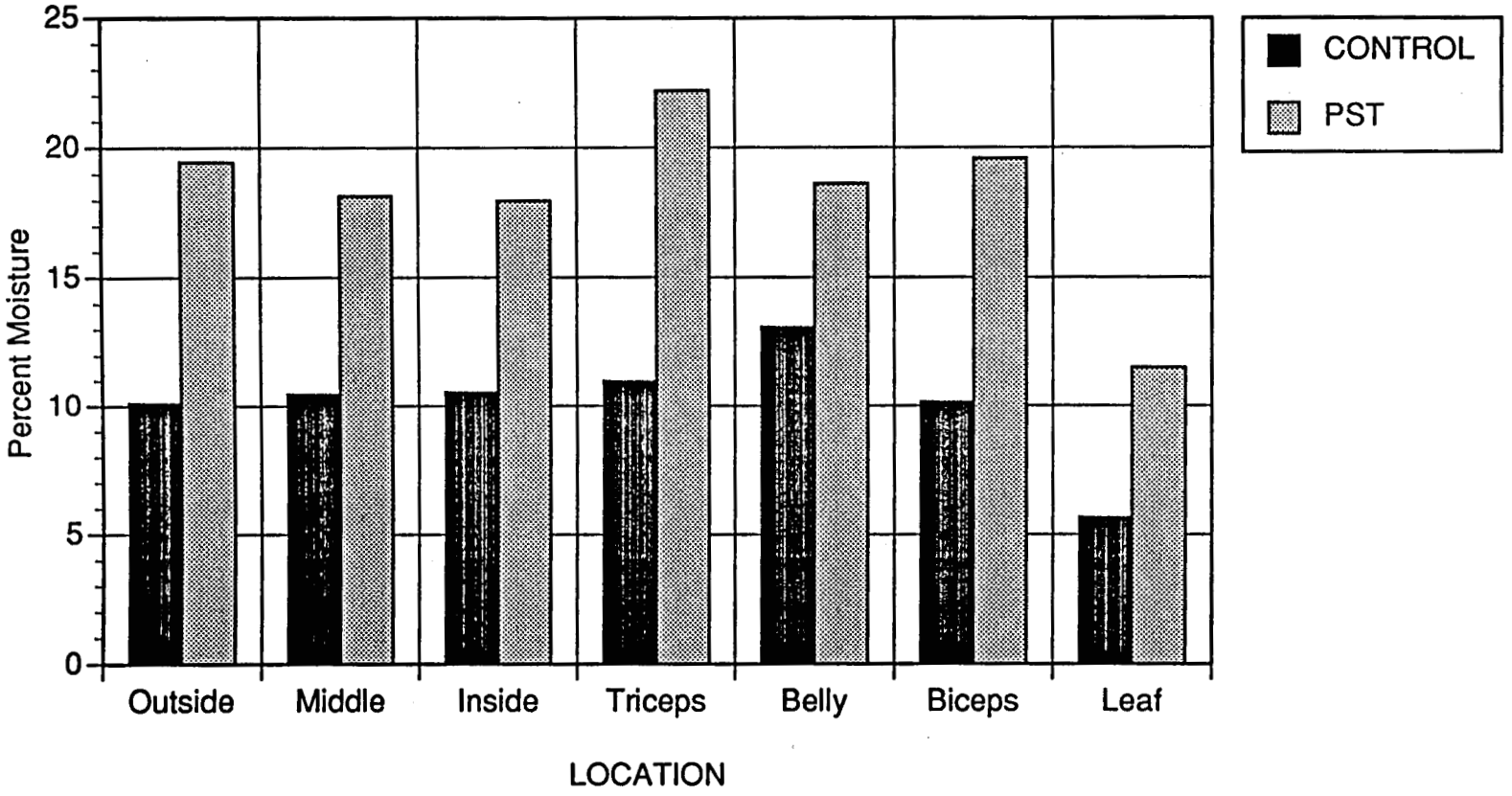
	CONTROL	PST-TREATED	SEM[e]
Before drying			
Moisture (%)	59.17	60.42	0.54
Protein (%)	16.61	17.01	.37
Crude Fat (%)	20.07	19.46	.67
Moisture:Protein	3.56	3.55	0.04
After drying			
Moisture (%)	39.81	39.11	0.45
Protein (%)	24.72[c]	25.98[d]	0.22
Crude Fat (%)	30.61	30.54	0.74
Moisture:Protein	1.60[a]	1.51[b]	0.28
Percent Yield	67.40[a]	65.00[b]	0.27
Stick Hardness (kg)	8.34[c]	10.63[d]	0.75
Slice Hardness (kg)	0.55[c]	0.79[d]	0.04

[a-b] Means with different superscripts are significantly different due to PST treatment ($P < 0.05$).
[c-d] Means with different superscripts are significantly different due to PST treatment ($P < 0.01$).
[e] SEM is the standard error of the mean.

Table 7. Fresh and finished compostion, smokehouse yield and textural parameters of bacon from PST-treated and control pigs.

	CONTROL	PST-TREATED	SEM[g]
Fresh Belly[a]			
Moisture (%)	44.05[e]	52.07[f]	0.40
Protein (%)	10.57[e]	15.45[f]	0.19
Crude Fat (%)	43.78[e]	29.47[f]	0.53
Bacon[b]			
Moisture (%)	42.04[e]	49.95[f]	0.48
Protein (%)	12.83[e]	15.67[f]	0.21
Crude Fat (%)	43.68[e]	30.42[f]	0.68
Chilled Yield (%)	86.30	87.80	0.57
Hardness (kg)	6.99[c]	5.31[d]	0.22
Springiness (mm)	6.00[e]	3.09[f]	0.19
Thickness (mm)	26.50[e]	20.88[f]	0.47

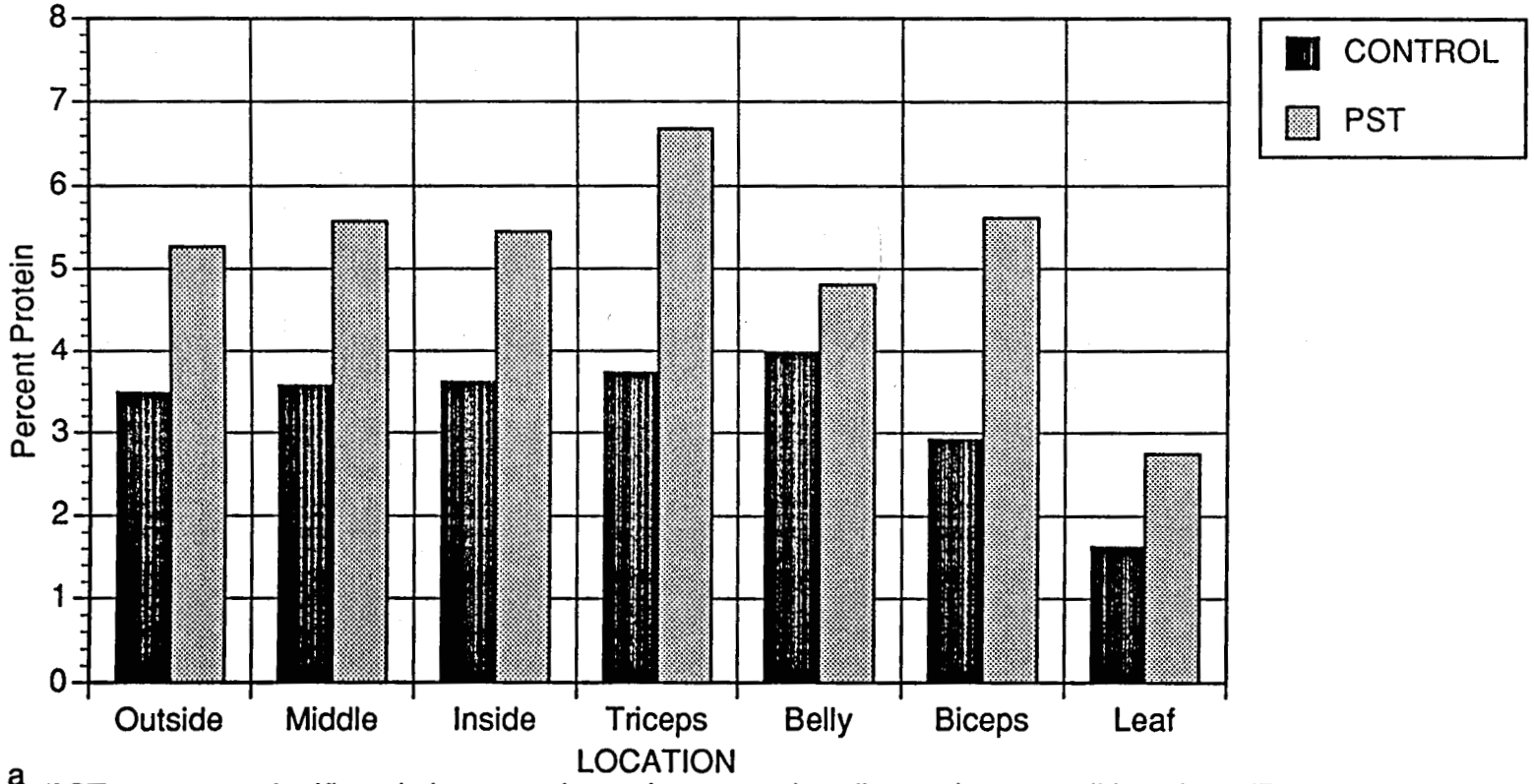
[a] Composition of fresh pork bellies (IMPS 408).
[b] Characteristics of cured and smoked bacon.
[c-d] Means with different superscripts are significantly different due to PST treatment ($P < 0.05$).
[e-f] Means with different superscripts are significantly different due to PST treatment ($P < 0.01$).
[g] SEM is the standard error of the mean.



[a]PST treatment significantly increased moisture content in adipose tissue at all locations ($P < .01$).

[b]The standard error of the mean for moisture is 0.25.

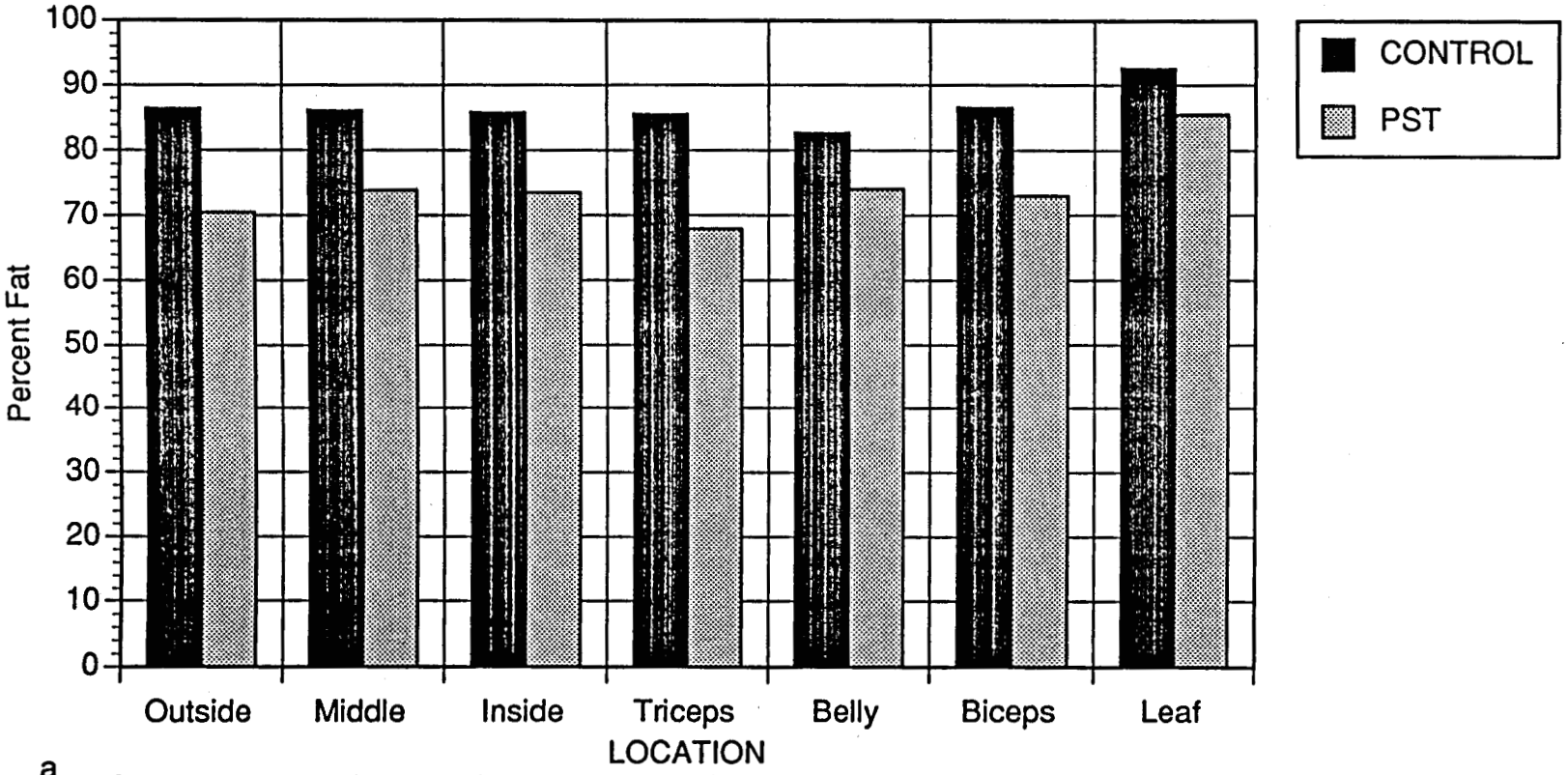
Figure 1. Effect of PST on moisture content in porcine adipose tissue[ab]



[a] PST treatment significantly increased protein content in adipose tissue at all locations ($P < .01$).

[b] The standard error of the mean for protein is 0.15.

Figure 2. Effect of PST on protein content of porcine adipose tissue [ab]



a PST treatment significantly decreased crude fat content in adipose tissue at all locations ($P < 0.01$).

b The standard error of the mean for crude fat is 0.45.

Figure 3. The effect of PST on crude fat content in porcine adipose tissue [ab]

GENERAL SUMMARY

Porcine somatotropin is a large peptide hormone that is synthesized in the anterior pituitary gland of the pig. Machlin (1972a) demonstrated that somatotropin extracted from porcine pituitary glands could be administered to growing pigs to increase growth efficiency, increase muscle growth and decrease lipid accretion. With the increased availability of PST through recombinant DNA technology, the interest in utilizing this growth enhancer in swine production has been renewed.

PST administration has been quite effective in increasing average daily gain (Johnson et al., 1989b), and improving feed efficiency (Etherton et al., 1986) in growing pigs. PST treatment of growing pigs has been shown to decrease total carcass fat (Ender et al., 1989a). Theil et al. (1990) demonstrated that PST treatment increase total separable lean in the pig carcass. Additionally, Ender et al. (1989a) observed an increase in the yield of primary cuts from carcasses of PST treated pigs.

While improved growth performance and increased lean production are indeed beneficial to the pork industry, the effects of PST on lean pork composition hold the greatest potential for the industry. PST treatment of pigs significantly decreased intramuscular fat content in fresh loins (Boles et al., 1990), hams (Beermann et al., 1990) and shoulder muscles (Prusa et al., 1989a). In addition, reduced fat concentration also results in decreased caloric content.

This reduction in fat and calories may increase the number of consumers that will include pork in their diet. The reduction of intramuscular fat by PST, though significant, does not appear to have an effect on sensory characteristics. of fresh pork (Prusa et al., 1989a).

Ender et al. (1989a) reported that subcutaneous fat from PST treated pigs was softer and contained higher concentrations of linoleic acid than fat from control pigs. Mourot (1990) observed similar effects of PST treatment on adipose tissue composition. An increase in polyunsaturated fatty acids may decrease processed pork textural integrity and flavor.

This project was developed determine the effects of PST treatment on adipose tissue composition and processed product characteristics. PST treatment did not alter the overall fatty acid saturation in subcutaneous or perirenal fat depots. PST treatment did, however, result in less fat deposition in the more saturated middle and inner layers of subcutaneous fat over the tenth rib. The more unsaturated outer layer of subcutaneous fat is then present in a greater proportion in the PST treated pigs. This may explain the apparent inconsistency with earlier reports of Ender et al. (1989a) and Mourot (1990). PST treatment increased moisture and protein content and decreased crude fat content in all adipose tissue sampled.

In this study, boneless ham characteristics were not altered by PST treatment. Because boneless ham is a lean product, the effects of PST on adipose tissue composition is not likely affect product texture.

Pepperoni formulated with PST-produced pork dried more efficiently than controls. This observation may be related to the original composition of the pepperoni. Further investigation of the drying kinetics of PST-produced pork would be a logical continuation of this project. If PST produced pork does dry more efficiently than conventionally produced pork, there may be several implications. Dry sausage manufacturers may be able to realize an advantage in shortened drying time. Second, a drying schedule may have to be altered to avoid the potential development of case hardening in a product that dries more quickly. A study that would examine the water holding capacity of pepperoni formulated with PST-produced pork should help develop a more clear explanation of what was observed in this study. Finally, this study should include an evaluation of the effects of PST-produced pork in a dry sausage that contains beef as well as pork. This component of the study may be able to determine how PST-produced pork may dry in a typical (beef and pork) formulation.

Ender et al. (1989a) suggested that utilizing PST-produce pork in dry sausage may result in a softer finished product. In this study pepperoni in the PST treatment group was harder than controls. This however may be a result of a slightly lower moisture : protein ratio in the finished product form the PST treatment group.

Bacon for PST treated pigs was softer and less springy than controls. This may be a result of an elevated moisture content in the separable fat of the slab bacon. If PST would eventually be

introduced as a pork production management practice, it may be necessary to change some current belly and bacon handling procedures to avoid problems that might be due to the softer less springy texture of the slab bacon. Bacon from the PST-treated pigs was significantly leaner, both chemically and visually, than control bacon. This factor should improve the marketability of the bacon from PST-treated pigs.

The textural differences in the processed products made from PST-produced pork are probably due to the proximate composition changes in the adipose tissue rather than an altered fatty acid profile.

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